OPTICAL MEASURING INSTRUMENTS.

Paper presented to the Institution, Coventry, London, Eastern Counties, Birmingham, Western, and Leicester Sections, by Franz Loewen.

THIS is a maiden occasion, if I may call it so,—the first meeting of the Session and the first meeting in this room, and I shall endeavour to live up to this maiden occasion by presenting something to you which has not been published before, and which, I hope, although it may sound a bit theoretical, has a good deal of practical value and application.

I propose to enter into my subject right away, and I begin on the first section with a definition of the term " measuring accuracy." It is a household word with all of us ; still, it contains more than meets the eye at the first glance. In fact, the term " measuring accuracy " is very frequently used without thinking that there are a good many conditions behind it which must be fulfilled to achieve measuring accuracy. I shall confine myself to the application of measuring accuracy of indicating instruments, as against fixed gauges.

The first contributary factor to measuring accuracy I should like to call " sensitiveness." The sensitiveness of an instrument is characterised by the smallest variation in the dimension which is to be measured that will produce a just noticeable movement of the pointer or index, relative to its scale ; in other words, the smallest alteration or variation of the length or diameter to be measured—that will make the instrument react at all.

" Sensitiveness " depends chiefly on design, on internal movement of parts, conditions of contact between parts, inertia of the various components, and on the ratio of transmission.

The second factor we call " reading accuracy." This can be described as the smallest fraction of one division on the scale to be safely estimated. As you know, the standards of divisions vary very much. On the whole we can safely say that the size of one division on the scale should be about 1 mm., or not much below, then you can safely reckon that one-tenth of one division can very well be estimated by a skilled person. It does not make any difference

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whether the scale is actually divided in intervals of 1 mm. each, or whether it is a smaller scale magnified through a microscope so that each interval has an apparent width of 1 mm.

The reading accuracy depends very much on the quality of the lines, on the placing and on the visibility of the lines against their background. There has to be considered the so-called parallax, that is the difference between the plane of the index and the plane of the scale ; if that difference should be considerable it might lead to reading errors.

The third factor is the " instrumental accuracy," and its reciprocal equivalent " instrumental errors," producing deviations from the reading one would expect theoretically. Again, the instumental errors are derived from internal imperfections of the instrument ; they are never entirely absent, even in the best of makes, but as long as they are kept within limits they may be considered harmless. They are the chief source of trouble if an instrument does not repeat, if the readings show an excessive amount of straying.

Taking the three points together, we come to the term "aggregate accuracy," which represents the sum of the previous three items ; but it would be inaccurate to add the first two in their full value, because it can be proved by the mathematical law of probability that it will hardly ever occur in practice that all errors will add up to their full value. It is safe to assume that the sum of those two errors will not amount to more than about two-thirds of their total value.

We have tried to explain these definitions by way of graphs :—

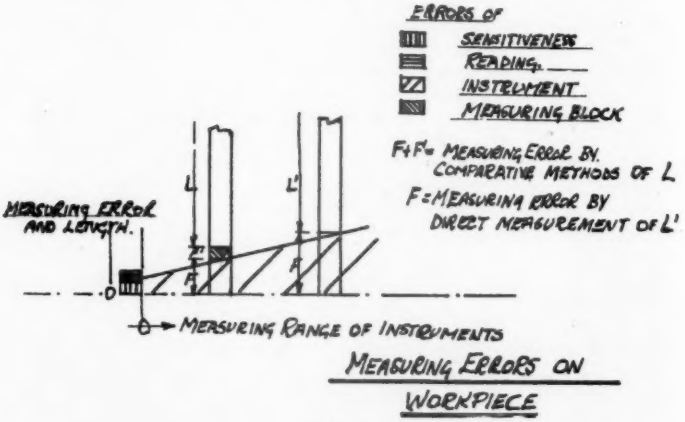

Fig. 1.

In Fig. 1 one shading shown on this graph represents the sensitiveness of any instrument. (This is a general case and must not be taken as referring to any particular instrument.) Another represents the reading errors, and you see from about two-thirds of this we start a curve, which represents the instrumental errors which increase with the size to be measured. The horizontal line represents the dimensions to be measured. Another line represents the error which may be expected if a given length is measured by one particular instrument.

The graph also shows lines F and F1. This applies to absolute measurement, whilst the first part applies to comparative measurement. F plus F1 is the measuring error, whilst for absolute measurement we read F only.

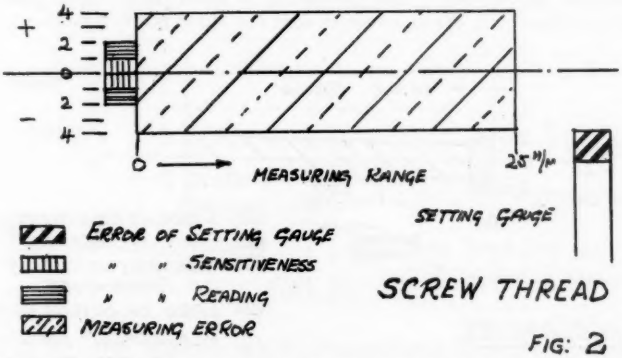

FIG: 2

Fig. 2 shows the same thing applied to a micrometer—one shading giving the sensitiveness; another the reading error, drawn above and below the zero line, which means errors have to be understood as plus and minus values. The errors are constant over the total range of the micrometer. Therefore the lines representing measuring error are parallel. The possible error coming from the setting gauge is also shown. The total errors to be expected can be read off the graph.

In the case of another micrometer (*not illustrated*) we have drawn the curve showing the pitch errors of the micrometer spindle. The errors start from the sum of reading errors and sensitiveness, and to them are added the pitch errors. Consequently, this will give the total measuring error in any position of the micrometer spindle. Here we need not bring in the setting gauge.

The Passameter, an indicating snap-gauge has an indicator, connected with a spring-loaded anvil, against a stop, and adjusted to a standard or slip-gauge. By putting in the slip gauge and moving

the locking screw, the pointer is put on zero. The piece to be checked is put between the anvil and the pointer will show the deviation from the standard. This is an instrument especially suited for cylinder grinding, in so far as it enables the operator to watch his job before he comes to the final operation. When the pointer approaches the field of tolerance, he throws out the feed and is sure to be within the tolerance required. This instrument is made in different sizes—up to 6 in. capacity, and is specially designed for external measurement. A button is intended for retracting the anvil, so that the gauge can be passed over the job without using force. The measuring faces are covered with tungsten carbide.

In the Passimeter—the corresponding instrument for measuring bores—the mechanical movement is practically the same as in the previous instrument. The measuring is taken over three points, two are fixed and Widia-covered, and the third is adjustable.

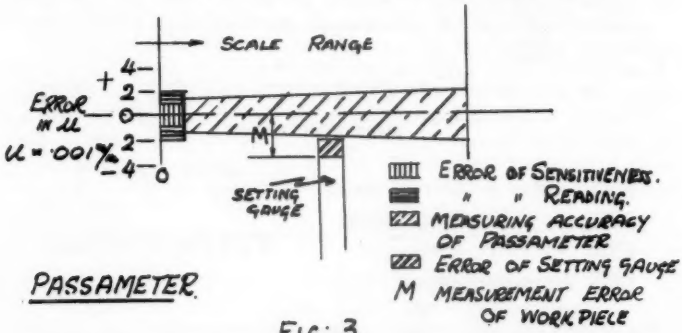

FIG. 3

The diagram shown in Fig. 3 applies equally to the passameter and the passimeter. The errors to be expected are marked in 1,000th mm., and it shows the same combination of sensitiveness, reading accuracy, and instrumental accuracy, influenced by the error of the slip gauge, used for adjusting the passameter or passimeter to zero.

Then there is an entirely different instrument—the length measuring machine. This instrument is intended for measuring length by means of a precision scale, which is situated in the bed, illuminated from the rear and observed through a microscope. This shows the full inches and their tenths and hundredths, whilst the thousandths, and ten-thousandths are read in the optimeter indicating instrument.

The main factor on this machine is the very ingenious optical system. It is independent of distortions in the bed. This has the

tailstock and the headstock carrying microscope and optimeter. The main scale consists of mild steel, with windows at intervals. In each window is a double line mark, and the image of this double line mark in the window is projected into the plane of another scale so that they are observed at the same time.

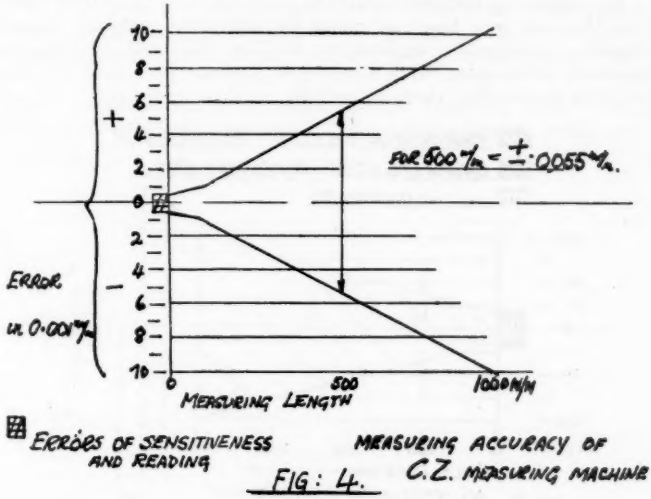

FIG: 4.

Fig. 4.—This machine can be characterised by a graph of this kind. Here we have to deal with greater lengths. The shortest machine goes up to 40 in. The initial errors of sensitiveness and reading accuracy amount to comparatively little, whilst the instrumental errors appear much larger. This curve has a kink, produced by the fact that up to 4 in. the accuracy can be guaranteed to a closer figure than for lengths above 4 in. Every smallest division shown represents .00005 in.

The Ultra-optimeter is specially designed for the comparative checking of slip gauges. Its ratio of transmission is very high—5,000 to 1. Hundred thousandths of an inch are read immediately on the scale. It is very sensitive to variations of temperature, even the heat which emanates from the operator's body must be kept away from the instrument by the glass screen which absorbs heat rays. There are a pair of slip gauges, (1) the master, and (2) the slip gauge to be checked against the master. This checking can be done to an accuracy of below .00001 in. The source of light is placed far away from the working field.

The contact tip is operated by a Bowden wire, which also prevents the operator from influencing the measurement by the warmth of his hand. The movement of the slip gauges is effected from outside by a fork, so that every precaution is taken not to interfere with the measurement.

An interesting feature is that the post, made of solid steel shrunk into the cast iron base will show its deflection touched, however slightly, considerable movement will be observed, showing the elasticity of the post. Such a steel post is generally considered rigid, but this shows that there is nothing rigid in designs.

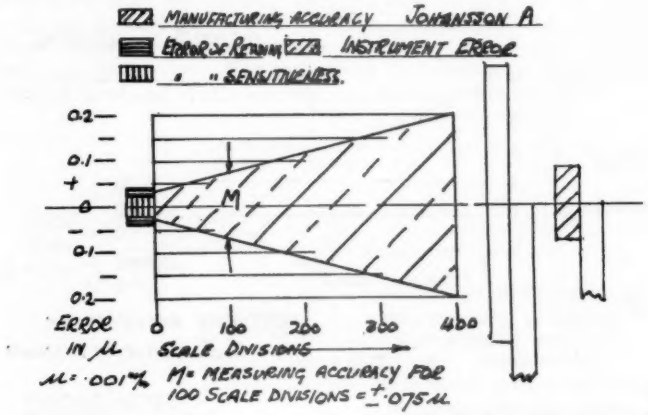

FIG: 5 ULTRA OPTIMETER

Fig. 5 shows the same method of representing the measuring accuracy—sensitiveness, reading and instrumental errors, and the errors of the master gauge in tenths of a micron.

This is an attempt to show you what can be done by this method of analysing the term of measuring accuracy in application to particular instruments. The idea is really to provide you with a means of judging and criticising, also selecting an instrument for a given purpose.

In order to obtain a good measuring result, external conditions have to be taken into account, chiefly imperfections of the object to be measured—its shape, whether truly round, truly spherical or truly cylindrical ; the surface of the object—whether it is roughly machined, or lapped. Then, personal errors enter into the picture very much—errors of eyesight—all effect the final result. And last but not least, temperature. This is one of the most important

factors affecting measuring, and I believe it will be found more and more necessary in the gauge department to provide temperature-controlled rooms, where this has not been done so far. In our works, we have installed several temperature-controlled rooms, and humidity is controlled as well.

I should not be surprised to see that machine tools of the highest precision, such as jig borers and thread grinders, will be erected in temperature-controlled rooms, perhaps in the near future.

(*This concluded the first section of Mr. Loewen's paper. In a further section various instruments, illustrated by lantern slides, were described.*)

Discussion, Coventry Section.

MR. HARLEY (Chairman): I think I may safely say that my prophecy of a very interesting evening has been amply fulfilled, and we are very greatly indebted to Mr. Loewen for his paper. One point that impressed me particularly was his reference to the question of importance of temperature in measuring and the fact that before long we shall probably all be faced with the necessity of having to instal rooms where the temperature is controlled to a very fine point. In this connection it is probably sometimes not fully appreciated why this temperature factor is of such importance. Probably this importance is somewhat exaggerated when all work is being carried out on the same type of material, i.e., steel; but once the materials differ—supposing you are measuring aluminium against steel standards—then the factor becomes very important when you realise a difference of 5°C. means at least half ten-thousandths in the accuracy of the measurement.

Another point I would like to mention is that accurate measuring equipment is sometimes not an expensive luxury. It must only be realised that if the degree of accuracy with which a measurement can be carried out is sufficiently reduced, then every amount that is saved in that error of measurement becomes available to the shops for production. It is no use having expensive equipment to do one part if you are content with gauges which have three ten-thousandths error.

MR. E. W. HANCOCK: I think we as an Institution—particularly the Coventry Section—are entitled to feel very proud that the first meeting held at the New Technical College has also been on the subject which I think will put to rights many of the critics of the Institution. Most people seem to have the false idea that the Institution of Production Engineers is a body of men with the sole object in life to make things for nothing.

I have worked with the Institution for something like eleven years, and my theme, which I would like to foster, is the importance of developing ability to produce accurately and to improve the manufacturing product. So far the designer in this country, as I know him, has not been able to catch the production engineer; he has been able to produce articles of the most exacting type and quality—and quantity, and it is very important that the Institution should keep its mind fixed upon this ability to produce quality equally as well as quantity. Therefore I think we are very indebted indeed to Mr. Loewen for coming here to-night and setting up this high standard to keep our minds associated with real engineering

accuracy as compared with the more "accountant" type of manufacture, which we sometimes have to cope with.

I would like to ask one question: What pressure is there on the anvils, on the assumption that one is measuring a ring of fairly delicate structure?

We, as production engineers, I think realise the one thing that Mr. Loewen has shown us this evening, and I do feel sure you will all support me in extending to Mr. Loewen our very great thanks for his lecture.

MR. LOEWEN: I thank you very much for your kind demonstration and applause. May I just answer that particular question, which is certainly pertinent. The measuring pressure is of great importance, and one can generally say a measuring instrument is all the better the less its measuring pressure. We generally endeavour to keep the measuring pressure of these instruments within, say, 8 to 12 oz., which has proved by practical experience to be satisfactory.

MR. DRANE (Section President): I thank you, Mr. Harley, very much for presiding over our meeting to-night. Most of us appreciate that Mr. Harley has cut out a little niche for himself in the engineering life of Coventry.

Discussion, London Section.

MR. J. E. BATY : Sometimes I feel that there is a want of appreciation on the part of many engineers of the great assistance that such men as Mr. Loewen have been to the engineering industry. We are really measuring manufacturers. If you talk to an unintelligent engineer about process measuring he generally thinks that you are laying some sort of a trap for him, whereas you may be putting into his hands something that will lead not only to more accurate work but also to cheaper production. I think one could truthfully say that time measuring is helping in the advance of all engineering manufactures. Quick and accurate measuring is just as important, say, for the motor car manufacturer as quick and accurate production.

I am very glad this evening that Mr. Loewen had laid stress on the question of sensitivity, the accuracy of the instruments, and also the personal error in taking measurements. This is not appreciated nearly enough, and it was sometimes a common policy that if a micrometer or a scale was graduated to read, say, in one ten-thousandths of an inch that the measuring accuracy of the operation operative on that machine would also be one ten-thousandth of an inch. To take an example of that, one could cite the tool makers' microscope that we have seen to-night. The machine there has an accuracy of one ten-thousandth of an inch, but they give the accuracy of determination of measurement on the external or root diameters of plus or minus five ten-thousandths of an inch, and pitch, of plus or minus two ten-thousandths of an inch, on an angle of either plus or minus two minutes. Now, an instrument with an accuracy of this order is all right, say, for the majority of threads that are made, but it is obviously not of the class required for production, where the limits on the gauge are of the same order as the possible inaccuracies of the machine.

Whilst speaking of the tool makers' microscope I would just like to say that whereas it is used as a projector the field is very limited and not readily acceptable for purposes of taking a measurement between a projected form and a master form. In many shops this type of instrument will satisfy all requirements ; but if screw gauges are to be inspected then I think that a projector similar to those designed by the National Physical Laboratory would be a great asset. The large field can be of very great advantage to an inspector. For this more accurate work I also feel that a pitch machine which has been specifically designed for taking pitch measurements is desirable for the work, rather than trying to do

all the operations on one machine. For example, taking pitch measurements on a machine of this sort we all know that if you have an inaccuracy of x over the length of a gauge on the pitch of your screw, then the virtual inaccuracy of the effective diameter on the male base is $2x$.

I am not competent to deal with all the instruments that Mr. Loewen has shown us this evening, and, if I were, there is not time to deal with them, but I would like to say that it does not follow that because all these beautiful instruments have been devised our previous mechanical methods are necessarily out of date or inferior to optical methods. Mr. Loewen has already mentioned that we must satisfy ourselves on the merits of each instrument by the use to which we propose to put it. I would just like to mention one or two examples.

Now for interior diameter measurements, particularly in ring gauges, the optimeter is no doubt a splendid machine, but for external measurements of screw gauges, say, screw plug gauges, I should certainly continue to use the types of machine as devised by the National Physical Laboratory in preference to any other methods known to me.

For pitch measuring in both internal and external screws I personally would prefer the types of machines also designed by the National Physical Laboratory.

In the case of external balance cylindrical work the optimeter would possibly be the best. For dividing, I suppose, the dividing head stands alone, but in checking up angular work I think I would certainly prefer, for the great proportion of the work, the ten-inch sine bar method, both from the point of view of accuracy and also for ease of handling. I do not know if Mr. Loewen is disposed to give us any information on the production of these instruments. I was hoping that he would mention them in the course of the lecture.

The one I am particularly interested in is the spiral ruled graticule. One can only test a spiral by marking every point on it, and as the master would have to be generated by the means of gears, and as graticules are made, I understand, by photographical processes, there would appear to be ample opportunity for errors entering into it. I believe they are extremely accurate, but if Mr. Loewen could tell us anything of their manufacture I think we would all be greatly interested.

Another point that occurs to me is the heating of scales during the operation of the machine due to the heat from the lamps. Is there any distortion of the scale where the apparatus may be in continual use? In the projection lamp used in the tool makers' microscope I noticed that they have a liquid condenser there, and

I wondered what the advantage was of that condenser that Mr. Loewen has been good enough to mention.

There was one matter which he mentioned during the early part of the lecture where he was referring to discerning a scale with the eye, and he thought that one could read fairly easily one-tenth of a millimetre, i.e., that you could subdivide a scale by judging that amount. Well, that one-tenth of a millimetre actually works out to four-thousandths of an inch, and whether it is easy to see between this four-thousandth of an inch and that four-thousandth of an inch I have a little doubt in my mind.

I would like to say how much I have liked to listen to Mr. Loewen this evening, and I should think that it is an achievement that he has spoken so lucidly and fluently in what is, I suppose to him a foreign language. I think it has been an excellent lecture and I would like on my own behalf to thank him.

MR. LOEWEN : I have to thank Mr. Baty for his appreciative remarks. Coming to the first part of those remarks of Mr. Baty's, I should like to point out that the instruments designed by the National Physical Laboratory are most admirable, and we are certainly amongst the first to appreciate every work and every method produced by the N.P.L., but as regards the use of projection where the accuracy is concerned I am just a little doubtful as to whether projection is really the best means of attaining this. After all, a projected image is generally not quite as clearly defined as an image observed directly through a microscope. The contours are never as sharp. Furthermore the grain of the screen used for projection helps to blur contours slightly. When it comes to the discerning and to the measuring of very small units of the order of one ten-thousandth or even half a ten-thousandth of an inch it is our opinion that projection should not be applied to them. In fact, as a general rule, we would advise where there is a higher accuracy to be determined than one-hundredth of a millimeter projection cannot very well be recommended. Perhaps views are different on this point, but I just make this remark in reply to Mr. Baty.

Then on the other question of making graticules. Graticules and scales can be made photographically, but it is not just a simple process. To begin with, the master from which the graticules have to be reproduced must be drawn on a very large scale, and with a very high drawing accuracy, which can only be achieved if the draughtsmen use a magnifier. Reproduction has to be done by means of a photographic process of a very high order of accuracy, free from distortions and producing a plain image.

The spiral of the optical micrometer is drawn with a diamond, the other lines are produced by the photographical method. Of course, the diamond on a good dividing machine is always the most

accurate means of producing divisions of any kind. By the way, those spiral lines on the graticule have been checked over and over again by people most competent in dealing with this sort of problem, that is, astronomers. We have had those spirals checked by astronomers independently of our own work and they have found that their degree of precision is quite satisfactory. I believe that will satisfy your question, Mr. Baty.

Now, as regards the heat radiated by the lamps used in illuminating the instruments and the scales. Of course, we take care to use a kind of glass for those scales which has about the same coefficient of expansion as steel, therefore any contraction or expansion of the glass would not affect the measurement, as the object to be measured is, in the vast majority of cases, made of steel too. But all that really does not amount to much if the fundamental rule is observed of measuring at the temperature of reference or very close to it, and in any reasonably well equipped shop with a good measuring or inspection room it must be laid down as at least highly desirable to have the temperature controlled accurately to at least plus or minus one centigrade. This can be perfected to a higher degree if necessary, but that means excessive expense for a machine shop, such as a motor factory, ball bearing works, or the like. I think that an accuracy of temperature of plus or minus one degree is all that can be desired within reason.

Now, as regards the heat radiated by the projection lamp on the tool makers' microscope, there is a condensing system in them to make the light parallel where it skims the object to be measured. In addition to that condensing system there is a glass vessel containing either distilled water or a very weak solution of sulphate of copper, about $\frac{1}{2}\%$ solution, which absorbs the heat rays.

In order to avoid the undesirable effect of heat it is becoming practice to fit the instrument with a hand-worked switch, and only switching on the light during the period of setting the microscope and reading.

I have seen experiments carried out, in fact, at Messrs. Brown & Sharpe, Providence, where they have observed the effect of the illuminating lamp on the universal measuring microscope, and by setting about very carefully and going into the finest details they have discovered what the heat radiated from the lamp will do; in order to obviate these however slight effects, they have mounted a hand switch, the short timed illumination has proved quite satisfactory, and the heat radiated by the lamp has then been found never to affect the measurements. It is now our practice to provide small flash light bulbs as source of light with negligible radiation of heat.

And now allow me to deal with the point raised by Mr. Baty as regards the estimation of the fractions of a division. As far as I

am aware, and I believe it is quite an established practice to say, that you can easily estimate one-tenth of one division of one interval on a scale if the interval is not below eight-tenths of a millimetre, and I believe this is derived from some physiological conditions of the eye. I feel sure that one tenth of a millimetre can always be estimated by a person fairly skilled and with a fair amount of routine in this class of work.

MR. ROLT: It is a great pleasure for me to come here to-night, particularly as I have watched the progress of the design of the Zeiss instruments from the time Mr. Loewen mentioned, about 1919 or 1920. Mr. Loewen is, I may say, an old acquaintance of mine. We have met fairly often and have discussed the various merits of the instruments we have seen on the screen to-night.

I was very glad when Mr. Loewen started his paper by laying down a few fundamental principles with regard to the accuracies of instruments. There is a good deal of misapprehension with regard to the accuracy of an instrument. For example, some people think that if you take an ordinary dial gauge with a dial about 2 in. in diameter and enlarge its dial to about 4 in. that you will get twice the accuracy out of it. That, of course, is wrong. The accuracy of such an instrument depends to a large extent upon the accuracy of the internal mechanism of the instrument, and it is a fallacy to magnify the divisions on the scale beyond a reasonable limit. Otherwise what you do is to magnify the errors inside the instrument and make them more apparent. Moreover, it is deluding to a person who may purchase the instrument, as he is likely to think that if he can see the ten-thousandths of an inch more clearly he can really depend upon those ten-thousandths.

Mr. Loewen mentioned fairly early the question of surface finish. He said that the degree of accuracy to which you can measure any particular object depends upon the type of surface it has. This is quite true, and surface finish is a subject which has prominent notice amongst production engineers. It is quite obvious that it is useless to specify articles with a tolerance of one-thousandth of an inch or so without specifying what type of finish is to be put on those articles. The difficulty at the present moment, I think is to be able to specify the finish in figures. There is a certain amount of work going on with the object of reducing this idea of finish to what one may call figures, but that cannot be done until some satisfactory methods are established for measuring finish. At the present moment, I think I am right in saying that methods of measuring finish are still in the experimental stage. I think, however, Mr. Loewen might have something interesting to tell us with regard to some instruments which Messrs. Zeiss have designed for this purpose. If he has I should like to hear about them.

The question of the effect of temperature upon measurements has been mentioned, and it really is nowadays of vital importance. As we all know, the standard temperature for measurements is at the present moment 68°F., and it is now the international temperature. In other words, if your buy a 1 in. block gauge in Germany it will measure the same size as one bought in the United States or in this country. It was only a few years ago, of course, that in Great Britain the standard temperature of measurement was 62°F. The yard is still defined as a length marked on a certain bronze bar when it is at the temperature of 62°F. but that does not conflict with the statement that the present standard temperature of measurement is 68°F.

Another point which struck me in Mr. Loewen's lecture was the mention of commercial guarantee. Now that is a point which has always struck me very favourably with regard to the Zeiss instruments and the Zeiss productions. You take up one of their pamphlets, and I might say I consider they are exceedingly well-written—anybody can understand them—and you have the methods of using the instruments carefully outlined and, moreover, you are told quite clearly what accuracy you can expect from the instruments. I think some British manufacturers might take that to heart because many still offer you instruments in their catalogues and say nothing at all about the accuracy you may expect from them. That often leads to trouble. The purchaser gets an instrument and he tries it, and, for some reason or other he becomes dissatisfied, and then there is a squabble between the manufacturer and the user. I think that it is much better for the manufacturer to put down the figures of accuracy right at the beginning, and then everybody knows what to expect.

I think I may say that my experience has been that the guarantees offered by the Zeiss firm on their various instruments are quite conservative. What I mean is that there is what Mr. Loewen calls a factor of safety behind them.

One very pretty example, I think, of the use of optical measurements in simplifying and increasing the accuracy of work is the optical dividing head. That, as Mr. Loewen so ably explained, comes down to merely viewing a divided glass disc which is produced very very accurately. The question of errors in gearing is entirely eliminated. That, in my mind, is what one might call the prettiest optical instrument in the Zeiss series.

With regard to angular measurements, I think it is generally considered in this country among tool makers and gauge inspectors that the most accurate method of measuring angles is by what is known as the sine bar. This, as you probably all know, is a bar with two buttons spaced at exactly 5 in. or 10 in., and the setting out of angles is done by means of block gauges. The accuracy of

this method of setting out angles is very high, and generally speaking I myself prefer that method to the use of any circular scale, the reason being that the tool you are using is a thing that you can check yourself and verify its accuracy.

We have been speaking mostly of optical instruments, but I think it is correct to say that a good many of the Zeiss instruments are purely mechanical. The orthotest, for example, is a purely mechanical type of indicator which I think Mr. Loewen told us indicates to half a ten-thousandth of an inch, and that it can be read by subdivision to one-hundred-thousandths. From personal experience of that instrument I can testify to its robustness. It is an instrument that can be put into a shop and can be used without a great deal of care. It is possible to flick the lever up and down without causing any harm.

The horizontal optimeter is an instrument which, as Mr. Loewen pointed out, seems to have a good many uses; yet my personal feeling about measuring instruments is this, that I like a measuring instrument to do one job and to do it thoroughly. That is the general principle on which the N.P.L. measuring machines are designed. When we have the job of measuring, shall we say, batches of 10, 20 or more screw gauges, we find it pays both as regards the accuracy obtained and the training of the people who use the instruments to design one machine for measuring the diameters carefully, another machine for measuring the pitch, and another for inspecting the form of the threads. I should not feel happy myself with an instrument which had to be used for a variety of purposes. Possibly that is merely a matter of taste, but I just mention that point.

Turning to the question of examination of screw threads by optical projection, there seems to be some little misapprehension as to the practice at the N.P.L. I think I am right in saying that the practice of examining screw threads by projection was first introduced at the N.P.L. about 1916. We use the optical projection aparatus solely for examining the general shape of the thread; and we usually consider that it is not possible to obtain an accuracy much closer than about three ten-thousandths of an inch, working at a magnification of 50 diameters. Where we do claim a higher accuracy is in the measurement of the diameters, which is done by mechanical methods. We only use the projection apparatus and optical methods for viewing the profile.

It is perhaps not generally known that when you project an image of a screw on a screen, what you see is not exactly the true profile of that screw. Even if you incline your light in the right direction, it is impossible to project on the screen the exact true section of the screw. That is one reason why the accuracy is limited to about three ten-thousandths of an inch.

Messrs. Zeiss get over that difficulty when they use the optical method for measuring screws by applying a small blade to the flanks of the thread, so eliminating the effect of the rake of the screw. To my mind, however, that is not such a simple method of measuring the effective diameter as the three-wire or two-wire method of making the same measurement. That is the method which we use at the N.P.L. for measuring effective diameters of male screws.

MR. LOEWEN : I hope I am not taxing you unduly, but the point Mr. Rolt has just opened is very interesting, as are his remarks on the question of testing surfaces, and I should like to show you just a few more slides which I have held back in the expectation that possibly this subject of testing surfaces might come up. (*Slides were then shown.*)

MR. C. C. FERGUSON : In Mr. Loewen's talk he mentions optical measuring instruments in armament factories. He has just told us that it is very difficult to measure lapped surfaces. In view of that I wondered whether he had come across any efficient machines for measuring the internal diameter of rifle barrels or gun barrels generally, because in a modern .303 rifle it is extremely difficult owing to the rifling and lapped surface inside to obtain that measuring accuracy which is absolutely essential for mass production ; and further Mr. Loewen has mentioned the adoption of certain measuring processes in French armament factories, German armament factories, and Russian armament factories. I should like to know what type of measuring machines are used.

MR. LOEWEN : The question relating to the examination of rifle barrels I can answer in so far that there are various instruments. There is one instrument for inspecting the surface for corrugations. For marks due to faulty tools it is merely inspection of the internal surface of the rifle. There is another problem connected with that relating to the measurement of the rifling for diameter, and also for measuring the straightness of the barrel. Both the diameter and the straightness can be measured by quite straightforward optical means too, by using the so-called autocollimation process. In fact, on the occasion of the Olympia exhibition last year we had shown both of the instruments I have just mentioned for inspecting the internal surface walls and for measuring the rifling for diameter and straightness.

MR. GROOMBRIDGE (Section President, in the Chair) : Before concluding the meeting, I would like to mention one or two points. There is, undoubtedly, still something for which we cannot get a measuring instrument. That is, for deciding the finish of machined surfaces. It seems to me that this is left to an Inspector's judgment to define what is termed " finish." There is one particular company

that I know of who go to the trouble of keeping a very large sample room, and they display samples of nearly every class of machine work as a guidance for their inspection department. This is, undoubtedly, a very expensive method.

On the motion of MR. A. J. AIERS, a cordial vote of thanks to Mr. Loewen was adopted.

Discussion, Eastern Counties Section.

MR. K. JEWSON (Section President, in the Chair), after paying tribute to the very interesting lecture, and congratulating the lecturer on his extraordinary command of the English language, said there were three points he would like to raise, viz. : he did not think there was any mention of a device for measuring three-lip reamers ; secondly, he presumed the optical dividing head was not intended to supercede the ordinary dividing head ; further, there were some devices, like spirit levels, which could be used with a very great degree of accuracy. This was not always appreciated.

MR. LOEWEN : With regard to the measurement of three-lip reamers, although there should be no real difficulty in this, as far as I am aware three-lip reamers are not the rule. If they can be relied upon to be concentric with their centres, then the measurement is easy on the universal measuring microscope especially when a dividing centre is being used.

With regard to the dividing head, it was not intended to replace the ordinary dividing head. It does not lend itself to spiral work, but the optical dividing head has found its place next and equal to the ordinary dividing head in many instances.

Spirit levels are certainly accurate and reliable, and very useful, and can often be used in conjunction with mechanical or optical instruments.

MR. MURDOCH : We have listened with a great deal of interest to the lecturer's remarks on measurement by the passameter, and one would like to ask for what sizes he would recommend these should be used. There is also the question of variation in temperatures. With regard to the screw testing instrument, I should think there would be a great market for these amongst screw manufacturers, for we find there is considerable variation here.

MR. LOEWEN : The passameters are produced in six different sizes, up to 6 in. maximum capacity. Actually each individual passameter must be limited to a certain range, the smallest to $\frac{3}{4}$ in., the next to $1\frac{1}{2}$ in., the next to $2\frac{1}{2}$ in., and so on.

The question of temperature is indeed a very serious one. Regarding the passameter, we need not worry too much, especially where shorter objects are concerned. In the majority of cases we deal with steel parts, and they can be dealt with at room temperature. In greater lengths temperature is a very serious consideration. In a piece 4 in. long, a change of 1°C. produces a change in its length of roughly .00005 in. Temperature must be observed and controlled in the instrument room. We have developed

a system of temperature control by blowing air into the measuring room, which has been brought to 20°C. In summer the air is first cooled down and then brought up again to 20° and by this process the air is dried and there is no corrosion in the measuring room. We are able to control temperature to plus or minus one centigrade. This question will, I think, engage the attention of the production engineer increasingly, especially with machine tools and gauges.

Regarding screws, you certainly find when purchasing nuts from one manufacturer and bolts from another, each has different tolerances, but it largely depends on the class of work required. For aeroplane and automobile work such differences cannot be tolerated.

MR. RACKHAM: Regarding this question of temperature control, I gather you refer to control in the particular shop where the gauges are made, but what about a job itself which has to be tested in a varying temperature? You would get varying expansion of a job according to the temperature of the shop.

MR. LOEWEN: Generally speaking, the gauge and the job will be of the same class of material and can be expected to be of the same temperature when on the machine, but it is certainly a point to be borne in mind. Supposing you are running a job at high speed in, say, bronze or brass, and the part is heated up in the machine, when you apply a steel gauge which is cold, obviously errors will occur. Therefore, care should be taken with the job to inspect at the correct temperature, and not when heated up.

I have been asked occasionally what the difference of co-efficient of expansion would amount to. I have figured out that even in steel where the co-efficient may vary between 9.5 or 13.5×10^6, then the maximum difference is still only a small percentage of the alteration brought about by the change of temperature by 1°.

MR. DURRELL: How would you check up the taper of a three spiral fluted reamer?

MR. LOEWEN: You can only do it on the universal measuring microscope by taking the reamer between the dividing centres so that you can get an accurate division and set for each lip, setting the knife edge close to the cutting edge of the reamer. The second knife edge can be set to the thinner end. We cannot put them on simultaneously because of the pitch. Therefore, the diameter at the thick end has to be determined by itself, then the reamer would be turned through the pitch angle and the second reading taken at the thin end. This can be repeated on every lip, and the reading taken will provide you with measurements giving the radius of one diameter for each lip at either end of the reamer, and you can take intermediate readings also. This is not a quick production method. It might be worth while to examine the first one or two, and let the production go ahead. You can be fairly sure if you

examine every tenth. The checking need not be carried out through all stages. A quicker means could be found in the passameter.

MR. P. KEEBLE : When grinding a ring gauge, is it possible to get any instrument to check between parallel and size by means of an indicator ?

MR. LOEWEN : It is not difficult to check a ring gauge of this description with a high degree of accuracy on a horizontal optimeter, but to do the same checking while the ring is held in the internal grinder, I do not think can be achieved with the same degree of accuracy. There are grinders with measuring apparatus attached ; but I do not believe these will give absolutely correct readings on the diameter and on the cylindrical form. It may be one could make sure of the diameter but I very much doubt if the cylindrical form can be checked with the same degree of safety. Accurate measurements of this kind can hardly be expected on the grinding machine itself. At the moment I do not know of any machine I could suggest to answer both conditions. One could imagine an indicating instrument built into a machine, but this would have to be specially mounted, as otherwise additional errors would creep in which would be difficult to control. It is an interesting problem, and might be looked into, although I do not know of anything to suggest at the moment. A beginning has certainly been made to build optical instruments into machine tools but the field of these is restricted, the general application is to be found in screw thread grinding.

MR. KEEBLE : If the ring gauge is bolted on the face plate of the grinding machine, would it be possible to undo that plate and have it projected on to a screen to give the size ?

MR. LOEWEN : I can tell you at once it is not possible to do it by way of projection. A ring gauge does not lend itself to accurate determination of its diameter by projection. It can only be done by contact measurement. If the gauge can be taken off the machine altogether and then put on to an indicating instrument, this would certainly be more satisfactory and more accurate. Projection I would rule out entirely.

MR. JEWSON : I am sure we could go on putting questions to Mr. Loewen and obtaining illuminating and interesting replies from him, until a late hour, but the time has gone, and from the Chair I would like to express on your behalf to the lecturer appreciation and thanks both for the lecture and for the way in which he has answered the queries put to him.

MR. LOEWEN suitably replied.

Discussion, Birmingham Section.

MR. E. P. EDWARDS (Section President, in the Chair): Mr. Loewen's lecture shows us how quickly optical measurement has developed, In my earlier days I was engaged in the screw business, and I remember that one of our greatest difficulties was the accurate measurement of screw threads. At that time the only means we had of measuring was projection, and I would like to ask Mr. Loewen what, in his opinion, is the comparative accuracy between the best type of projection and the actual direct measurement which we can now obtain ? I should like to ask also what effect temperature will have on accuracy in connection with the glass scales used in the instruments he has illustrated ? It did strike me as being a remarkable fact that with this instrument, using ordinary labour and taking two different men, it is possible to get down to readings only .00005 in. apart. I also understood Mr. Loewen to say that, in checking gears by the knife edge method, the want of concentricity of the gear was not affected by the instrument.

MR. LOEWEN: In reply to Mr. Edwards' first question, I can give an average figure. If we compare the checking of screw threads by means of projection and by means of the knife edge method, that is with a Universal measuring microscope, we can assume that with projection we cannot get better results than plus and minus .0004 in. whilst with the other method we can easily obtain plus and minus .00004 in. so the accuracy in the latter case is about ten times as great.

Projection altogether is a very useful means of measurement, but it is more a convenience than a means of high precision. On principle, one should never expect an enlarged image produced by way of projection to give inherent accuracy, and by enlarging the projected image this is certainly not obtained. It is just as if we were to extend the hands of a watch by a foot. We should find it easier to observe the fractions of a minute on it, but the accuracy of the watch mechanism is not increased.

Coming to the second point, the effect of temperature on the glass scales, the glass employed for these is specially made with a view to keeping the coefficient of expansion very close to the average coefficient of expansion of steel.

The third question, measuring the base circle pitch of gear teeth, it is indeed independent of errors of concentricity, because those parallel tangent blades on the involute are equidistant irrespective of the point where they actually touch the curve. Therefore if there

should be an error of concentricity, the measurement of base circle pitch is not affected.

MR. JARVIS : Our lecturer this evening has mentioned that the nature of the surface of the scale and type of line used affect the accuracy of the instrument. Would he just amplify that, in the direction of saying just what is a good line and a good surface, and what constitutes a bad line and a bad surface ?

MR. LOEWEN : There is a large variety of ways in which scales may be made. They can be engraved, they can be etched, they can be drawn with a diamond point or steel tool, they can be made of metal, brass or steel, of glass, of quartz, and in every case the line will be different. The smallest width of scale line drawn with a diamond on glass is, if I remember rightly, about three microns, .00015 in. The lines, for instance, used in ordinary slide gauges are generally, on the better class instrument, produced with a small circular saw or drawn with a steel tool. The common quality can be produced even by rolling the graduations on to the instrument, but that cannot be considered a practice of high precision. The accuracy obviously depends on the width of the lines to a considerable extent. If the width of the line is comparatively large in comparison to the width of the interval, then of course no great precision can be expected. Then again, lines drawn on metal surfaces show up very differently. For instance, a dull silver finish, or nickel finish, even a dull chromium finish is a very good background for black lines. In optical instruments green forms a very good background for black scale lines. There is also a process of printing divisions on scales. For instance, the dials of dial gauges are generally made by a sort of printing process, but I cannot tell you details of this process. The enormous precautions that must be taken in the production of glass scales is illustrated by the following curious occurrence. These glass scales are produced on a special machine which is situated in a temperature-controlled room where the operator must be safe from any disturbance. Next to that room a telephone was fitted without the knowledge of the operator of the machine. The telephone rang for the first time, the man got just a slight shock, and the scale he was working on was spoiled because of the small movement he made with his hand at the moment. If there are one hundred lines on the scale, of which ninety-nine are right and the hundredth is wrong, the scale is useless.

I would add that those divisions read with a Vernier deserve careful consideration for the following reason. The lines of a Vernier should be as close as possible in the same plane as the main division, because any set off between scale and Vernier produces parallax. By parallax we mean the apparent shifting of the Vernier lines relative to the main scale lines if they are viewed from one side or another.

When sighting over a window frame to the edge of a chimney and shifting the eye sideways you notice an apparent shifting between the window frame and the chimney. The same thing occurs in the use of the Vernier. The optical instrument scores easily over the mechanical Vernier, because here both scale and Vernier can be brought absolutely into one plane and no parallax should occur.

Parallax can easily be observed in optical instruments by just shaking the head whilst looking into the eyepiece. Should the lines move apparently relative to each other, then you can be sure the instrument has not been exactly focused. One should begin re-focusing the eyepiece and then focus again on the object until the object's contours or lines appear equally sharp and no relative shift takes place between the eyepiece lines and the object contours or scales relative to each other.

A VISITOR: On the subject of projection, I have to use a toolmaker's microscope. The subject I have in mind is a cutter of which a graph was made up and placed on the screen, and then the cutter was placed against the screen. The way of checking it was by a slip gauge. The cutter was 30 times magnified. I found that when I got clear vision, it was under size. As I brought it up to size the background was misty and out of focus.

MR. LOEWEN: If you want to check a toolmaker's microscope, that can easily be done by projecting the image of a glass scale on to the screen and comparing the projected lines with another, preferably a glass scale. You will find that the magnification is very accurately determined and obtained over the whole centre of the field, but necessarily the field curves off towards the edge. That is a very serious problem in the design of optical systems altogether, because the various demands upon the different systems are confiicting. What we want is magnification, illumination, a certain diameter of the field of view; we want freedom from distortion and colours and a flat image. Now in order to reconcile all those conflicting conditions, it becomes necessary to compromise, and we must allow for a certain falling off at the edge. In the case of the toolmaker's microscope, distortion is avoided and you need not rely upon the edge of the field at all, because you can take your measurement in the centre of the field, by setting the points of your contour or form tool to the respective line of the protractor eyepiece.

MR. GIGLI: I think the matter can be cleared up in a different way. If the form tool was projected onto the screen 30 times full size, and it was too small, I think actually what was happening was that the screen was not in the right position. Unless it is exact magnification will not be obtained. The way to get over that is not to try to focus it to full size, but still to leave it sharp

and move the screen until the sharply projected image is correctly magnified.

In the tool maker's microscope, the post which supports the screen is eccentric, and it should be set to give the exact magnification.

MR. LOEWEN: I have assumed that the screen was adjusted in the right place. Certainly, by moving that eccentric pin adjustment the screen can be set to give exact magnification.

MR. LUNGMUSS: The advantages of optical measurement over Vernier have been mentioned. Will the lecturer give us some idea as to the advantages of optical measuring over other types, such as the minimeter and pneumatic gauge.

MR. LOEWEN: Probably many of you would be interested to hear what we have got to say about other people's instruments. I really do not like to get up here and give an opinion. I can only say that minimeters are certainly popular and widely used. We produce indicators which have certain special features of their own.

The pneumatic gauge is an interesting instrument. I had the pleasure of seeing it in Paris and having it demonstrated by the makers themselves. It is certainly an admirable idea, and I believe it has proved its usefulness in several instances, especially for the inspection of cylinder bores for combustion engines. Beyond that I have not come across any outstanding applications.

MR. BLACK: I should like to ask the lecturer why these instruments, of which we have seen so many, never tell us how or when a circle is round. I know very well that most instruments are two or three point type, but we get so many conditions where a circle is not quite round. The Solex machine tells us two points, the Zeiss machine tells us two points, but they do not tell us what shape that circle is! It is very important in some cases that we should have a means of measuring the true form of any given circle.

MR. LOEWEN: This again is a very interesting problem. If I may refer to the passimeter, this is a three-point measuring instrument. Other instruments can easily be used for measuring over three points by placing a cylindrical object in a vee.

What the gentleman is referring to is probably the ovality and lobe error. The ovality can be determined by a two-point measurement. The lobe error can only be determined by three-point measurement.

The lobe error had been very fashionable just recently. People have gone into the lobe problem and have published very interesting articles on the lobe errors of cylinders, of balls, and we know pretty well all about it. But when we come to look at it from a practical point of view, the actual lobe errors that occur in balls for ball bearings, say, are of very small dimensions and for practical work they are not really serious. Nor, I believe, are they very serious in bearings, and on spindles.

Components of which a high degree of precision, great speed, and true running is expected, are generally produced on good machine tools, and we can safely assume that in those machine tools lobe errors will be kept to within such low limits that the running of the machine will hardly be affected by such errors.

The determination of it is very simple, and can be effected by simply rotating a cylinder in a vee block, with an indicator on top.

MR. BLACK : I hardly believe the three-point contact quite gets over the difficulty I had in mind. I definitely believe it is necessary in many instances that we should inspect the true form as well as the single limits.

MR. LOEWEN : Do you mean by your last remark that you require an arbor, say, or a cylinder to be checked between centres, or do you object to three-point measurement in principle ?

MR. BLACK : I merely wanted to point out that when we check by either two or three points we do not cover the whole of the field. It is necessary, in my opinion, in order to get true accuracy, to measure the whole of the form. In the case of a screw gauge, some sort of final check is almost essential for absolute accuracy to prove it is exactly round.

MR. LOEWEN : I beg to differ. I do not believe that it is really a final check on all the other measurements. If you screw a ring gauge over any screw and it goes smoothly, that does not prove anything. You can have a very bad screw, full of errors, and still you can get the ring gauge to fit snugly.

I believe the individual tests carried out for defective form, pitch, diameter, and so on, are conclusive in themselves, and it is unnecessary to impose a final check of the nature you describe.

MR. BLACK : I did not say it would eliminate other tests. I agree that the other limits must be tested.

MR. LOEWEN : Can we agree to this formula, that if all the other checks are carried out, and have given satisfactory results, then the fit of the ring gauge will necessarily be satisfactory, too ?

MR. BLACK : I do not think so.

MR. LAURENCE : Mr. Loewen said there was a limit to projection. I cannot quite see that myself. He gave the example that if the fingers of a watch were extended they would still give the same degree of accuracy as the watch, but surely if the fingers were extended to infinity you would get an infinite reading of accuracy on the dial ?

MR. LOEWEN : It amounts to this. If we enlarge a watch dial to ten times its size, the reading will be a little more convenient, but the accuracy of the measurement of time could not be increased by such means. Take, for instance, the toolmaker's microscope. There you are working with a micrometer screw on the table. If you move the screen further back and get the projected image on a

larger field, apart from the effect of the loss in illumination because the same amount of light is spread over a larger area, the dimensions of the shadow image are drawn out, but you cannot make any more accurate setting, for one reason, because the contours of your shadow image will become more hazy the more you spread out the projected image. At the same time the micrometer mechanism of the instrument remains unchanged. That was the point I was trying to make.

THE PRESIDENT proposed that a very hearty vote of thanks be accorded to Dr. Loewen for his very able lecture.

MR. J. A. HANNAY : It gives me very great pleasure to second the President's very generous vote of thanks. I should just like to get some idea from the lecturer before he leaves us to-night, as to how long it takes the various people in charge of these instruments to settle down and give really definite and reliable reports? I must say I more than appreciate the way in which Mr. Loewen has spoken to us to-night. The field here is enormous. I would like to venture one thing, and say that our machine tool makers have got to start thinking!

MR. LOEWEN : I am obliged to the President and Mr. Hannay for their kind and appreciative remarks. If I may answer the question regarding the time it takes to train a man to use those instruments, I think a tool-maker, or a man trained to do this kind of work should be able to make use of those instruments inside one or two weeks, given proper instruction to begin with, and after careful reading of the book of instructions. There is not generally any difficulty in training a man to use these machines even if he has never heard or seen anything about them.

Discussion, Western Section.

MR. ROWBOTHAM (Section President, in the Chair): I am sure we are all very much indebted to Mr. Loewen for his very interesting lecture. Before he started his lecture he told me he might deal with the subject from the theoretical point of view or from the application point of view, and he chose the latter. It is for that reason he has explained such a large range of instruments. I believe that if any member likes to challenge him on the scientific or theoretical side he will do his best to reply satisfactorily.

MR. MOORE: What is the smallest size of ring the horizontal optimeter can deal with? Is it practical for the very small ring gauges?

MR. LOEWEN: The smallest size of plain ring gauges that can be dealt with is $^{17}/_{32}$ in., with a pair of special feelers $\frac{1}{4}$ in. There is a demand for accurate means of measuring the effective diameter of small female threads, but, gentlemen, I am afraid that so far there is no really satisfactory means of obtaining such measurements except by taking a cast, and that method is certainly not ideal. I can only suggest if that method has to be practiced, in preference to the usual material employed for making casts, I should recommend the use of "copper amalgamate." This can be obtained through the dental trade. It consists of 60% copper and 40% mercury, and if slightly warmed up, in the hand, or in hot water, it becomes plastic, and will give a good copy of female threads without shrinking unduly within a few hours.

MR. TAYLOR: Has the lecturer had any experience with the checking of the shape of involute teeth? This is a matter of great importance in the printing trade, in which I am interested, and we get a good deal of trouble through badly cut teeth causing marking on the printing. With regard to the lecturer's warning against the use of projection, I found this very interesting. As a matter of fact I came across a case once where projection was turned down as it was impossible to keep a record of any variation, disregarding the question of accuracy. I expect the lecturer knows that in the printing trade we find it very difficult to hold to the shape of involute teeth, and experienced manufacturers are able from long experience to match up faulty teeth with others that give a satisfactory result for printing purposes.

MR. LOEWEN: This is indeed an extremely interesting problem, and has engaged, and is still engaging, a great deal of our attention.

In fact the gear prob'em has not come to a final stage of perfection yet. Although I know gears can be produced with wonderful accuracy and finish. As regards the involute we actually make a special instrument that checks the involute and records its own graph. If the involute is accurate it registers an approximately straight line with an accuracy of .00008 in. Gear makers and users have replied to my question regarding it, " The involute is not worth so much trouble. If we have a good hob and hobbing machine, we rely on that process to produce a sufficiently accurate gear, or, if necessary, on the grinding machine." However, recently, this opinion has been subject to a change ; people are becoming more and more severe, and therefore interest in checking the involute has been aroused in circles where formerly it has been disregarded. I can quite imagine that the printing machine engineers get seriously worried about gears. I have some slight acquaintance with some printing machines. I do not know, however, any firms in that trade who actually go to the trouble of measuring the involute form of their teeth. However, on high class work this might be worth while, although I admit the primary investment for a machine to do this is comparatively high.

Mr. Kenworthy : Whilst listening to Mr. Loewen and seeing all his weird illustrations of scientific instruments, I was very interested in what he said, but I was also somewhat disappointed that his application of practically the whole of the apparatus has been for use in checking master gauges and master instruments and not applicable to general inspection. The only instrument useful for general inspection is the passameter and this is too intricate for general use in the shops, when it constantly requires re-setting. I think there is plenty of scope yet, in spite of all that firms of the standing of Messrs. Zeiss have done, in developing for shop use something more handy, and I think this is very desirable. The passameter is an expensive little instrument and to use it to the best advantage, it should be set and retained for a particular job, and this means having an enormous number in use. I think if it could be developed to be adjusted much more quickly, it would be a more effective and useful instrument. Another need is for an instrument similar to the passameter but for use in internal measurements for checking bores. I do not know of any efficient instrument on the market for that type of work. Also the passameter is not ideal for very accurate work. It only takes measurements in one plane, and a three point application is most desirable for measuring roundness and size.

Most of the instruments Mr. Loewen has illustrated are of an optical nature and I was rather disappointed he did not show us illustrations of the optical systems and the manner of reading the

scale. It is very difficult to realise from the pictures on the screen how such a high degree of accuracy is obtained as readily as it is, and how simply the readings are obtained. In the case of the gear testing machine for checking the spacing of the involute teeth, it was not clear whether it checked the spacing of each tooth separately, or whether it measured the cumulative error round the whole gear. I have seen similar instruments which check one tooth at a time, but not the cumulative error. Does the machine also check the shape of the tooth profile?

MR. LOEWEN: With regard to the remarks of Mr. Kenworthy on the subject of the passameter, I should like to point out that his perfectly justified claim for three-point measurement is fulfilled by the passameter by the addition of a fixed stop on the passimeter body so on that point I can satisfy him. The passameter can also be set for different sizes very quickly, in fact the passameter is very suitable where there is a frequent change of dimensions because it can be so easily set to any size in a few seconds. The setting of the tolerance is also done very quickly and I think Mr. Kenworthy overestimated the time taken for setting.

He asks a further question with regard to internal measurements. We have a machine for this and while we call the machine for external measurements the passameter we call the one for internal measurements the passimeter. This is essentially made as a three-point instrument, and is otherwise the same in its accuracy. The indicator is the same, but different heads have to be used. Internal measurement is more complicated and presents greater difficulty and therefore calls for more elaborate means. By the way, these three measuring point heads are disposed on the surface of a perfect sphere and consequently the instrument is not sensitive to little deviations from the straight. If the instrument is inserted in the bore slightly on the slant it does not affect the measurement. I have slides showing the optical system of the optimeter but I cut these out because I was afraid of taking up too much time. By the way, this is explained in our little booklet and from that I think it is quite easy to understand.

With regard to gear testing, we measure the space from one tooth to the next, therefore not the cumulative error which, however, can be determined graphically by plotting the readings. This gear tester is not mainly intended to check the involute, but it can be done indirectly by taking readings at three different places in the involute. If after plotting the result, the curves are similar one can safely assume the involute is correct. This is an indirect way but it is feasible if no other means are available.

MR. CURSON: When he was dealing with the horizontal optimeter Mr. Loewen referred to a method of measuring ring gauges. In taking the old fashioned method of inserting a lapped plug gauge into the

ring gauge, I would like to know what fit we might expect to get between a plug gauge of nominal size and a ring gauge of nominal size as measured by this instrument.

MR. LOEWEN: This question wakes rather pleasant memories with me, for the following reason. Three and a half years ago I was travelling in America. I visited a very important industrial centre and a man there seriously interested in measuring problems put the question to me: What would be the maximum accuracy to which you could produce a 2 in. gauge ring? He said he would not worry about the time taken or the price, but he would like to have a 2 in. ring as perfect as human science and means could make it. I took the matter home and discussed it with my colleagues, and eventually we decided to tackle it. We made a 2 in. ring; that was not difficult at all, but it was difficult to measure because in going into very fine measurements there was too much spring in the measuring feelers. We had to design new means, but we worked very successfully with the horizontal optimeter. During the process we had of course to make a corresponding plug, and the plug was measured and it was discovered that the plug was .00016 in. larger than the diameter of the ring; all the same it went into the ring quite easily. At first we were perturbed, and checked again, got the same reading; the plug was the same, the ring was perfect, but still the larger plug would go into the ring. To come to the bottom of it, we suspected elastic deformation, but to make sure, we lapped one face of the ring and the front face of the plug. We lapped them optically flat and checked them with optical flats. Then we inserted the plug into the ring and we put the optical flats on to these perfectly flat surfaces, they clearly showed distortion of the interference bands, bearing out our theory of elastic deformation of ring and plug.

The final result was that this 2 in. ring gauge had no greater error in size, roundness, and straightness than .000008 in.

Discussion, Leicester Section.

MR. J. H. BINGHAM (Section President, who presided): I make an admission at the outset that I know very little about this particular work, but having regard to the exacting conditions necessary in the use of some of the instruments which have been described to us, I am prompted to ask if their has been any attempt in the field of optical measurement to work in vacuum?

MR. LOEWEN: This is indeed a very important question, but why should we work in vacuum; why should we measure in vacuum? We have got to work under atmospheric conditions—probably there is no reason why we should not; if we could work in vacuum then it is a question of how should that vacuum be? It is really, I think, not so much the vacuum as it is of the atmospheric pressure, or low pressure, which determines our measurement. It is much more the determining factor than anything else. We have occasionally made attempts in that direction, and carried out experiments, but then only in connection with wave length of light, when the wave length was the determining factor.

As you know, the wave length of the various spectral colours has been determined with an enormous degree of accuracy, I think it was something like the eleventh decimal, and those determinations of the wave lengths of light have been made under various atmospheric conditions, but I think it is correct that those wave lengths of light should be expressed for 20°C. (68°F.), 760 mm. atmospheric pressure, and 50% humidity or 10 mm. vapour pressure. Those are the standard normal atmospheric conditions, which may be taken to be somewhere near the average in medium latitudes, and as the majority of industries are concentrated in those moderate zones on earth, it is probably the right thing to work under those conditions. By the way, it is only quite recently that the temperature of 68°F. has been agreed upon in England; it is only a few years ago. France used to be on freezing point, but all that has been changed to 20 centigrades, and we are really all very happy about it. We are happy about it because we can now work very comfortably at a normal temperature in the production shop.

It follows that the measurement laboratory should conform to those conditions. The best method, from our own experience, is to use conditioned air blown in, and controlled by automatic thermostats. With those means you can keep your laboratory, or measurement room quite easily at reference temperature. This is necessary, for instance, when it comes to measuring the absolute gauge length because of means of light interference with different

spectral colours; then it is necessary to determine the actual measurement temperature to plus or minus one-hundredth of 1°. In those cases, therefore, the temperature is even a more important consideration than otherwise for our industrial purposes, but then this rather constitutes exception. We, in our shop, for instance, have adopted temperature control, i.e., where we make slip gauges, also in our measurement laboratory, also in those rooms where we check instruments like length measuring. Machines and all products of a similar degree of accuracy. After the initial plant has been put in, it is a joy to work in there, and it gives you a feeling of certainty. You can rely on the plant, you can rely on your instruments, and you know the temperature will be maintained accurately whatever happens inside or outside, whether it is winter or summer, or whether there are one or ten persons in the room, the temperature will always be maintained, and although the initial outlay was very considerable, we feel we have made a step in the right direction.

Now coming back to your question; I do not think vacuum would be any help. It is difficult to produce, difficult to maintain, and, in fact, it would constitute a state of affairs different, very different, from the ordinary, under which we have got to work. Therefore, although for physical experiments, and research, it may sometimes be useful, for practical purposes which we are concerned with chiefly, I do not think it would help us very much.

MR. AUSTIN: Could Mr. Loewen tell us about affixing optical measuring conditions in actual production? Most of the cases which he has mentioned pertain chiefly to the two of them. Well, you have got to have something very good on the production side, otherwise you cannot keep to conditions.

MR. LOEWEN: It is indeed most desirable to produce instruments that are mechanical optical, or which can, shall I say, be added to the production machine. Although I must defend those instruments insofar, they are certainly not only, or exclusively, intended as suitable for gauge work and the inspection room; in fact the toolmakers' microscope, for instance, often finds its place very near to a screw grinder. Then we have even been asked—and we have done it—to produce microscopes that are built into screw grinding machines, just to keep in touch with this special item, because there it is comparatively easy and most necessary. The microscope, then, which is, by the way, a similar type to the toolmakers' microscope. In that case the form of the grinding wheel can be observed and checked. It is, of course, equally possible, and feasible, to check the thread, but obviously, in the first place, one would look after the grinding wheel, which is the most vulnerable part of the whole machine.

There are other possibilities on lathes in the ordinary way. On turret lathes I do not think there is much call for it, except for

indicators, then clock indicators are suitable. The mechanical indicator that I have shown can be used, and instruments of that nature for checking size, etc.

Then I have seen the optimeter used for the similar purpose also. There is sometimes a call for it on surface grinders, but then again it is the indicator that will generally work. The cylindrical grinder also calls for indicating instruments; in fact, many grinding machines are provided by the makers with several kinds of those indicating instruments. They are certainly very good but from my own personal observation—I believe I am not doing injustice to the makers of those machines and instruments—I have seen this extra tackle taken off, and tucked away in the tool corner, and when you asked the operator, "Why don't you use it?" he will give you a reason for not liking it. Now some of those are a bit clumsy, and probably do not react quickly enough to just a grinding job, so that may probably account for it. However, I have seen other cases where those indicators have been in constant use.

I do not know whether I made mention of profiles. You have to be very careful in those matters. I should not be surprised if some progress will be made within the next few years, it may be by the application of the full electric service. Many people are experimenting with it, nobody has solved it finally and completely, that is as far as I am aware at least. I know there are experiments going on in the United States and in Germany too, but I do not know what has been done in this country. I have information on the subject, it is being used, but in isolated cases, although it has not been developed and it is not for general application. I think we can look forward to interesting developments in that field within the next few years. I do not know how far our hopes will be realised, but it certainly seems a visible way to pursue. I remember one case, which was a grinding job, where profiles had been ground on. By the way, that reminds me of a very interesting application. There is a form grinder on the market sold in this country by Messrs. Alexander, of Birmingham. A magnified shape is placed on a drawing board, that shape is followed with a stilo, transmitted by a pantograph, and that pantagraph controls the movement of a slide whilst a grinding wheel is make a vertical movement. This is used for production of templates, form tools, and similar jobs and, in fact, produces a very nice class of work. Into this machine a microscope—a long microscope so to say, is built in the centre of the pantograph just above the grinding wheel; it only contains an ordinary cross line, and serves to locate the position of the grinding wheel to the job.

The same principle may be applied to other jobs of a larger scale, even where such a high accuracy is to be attained. It might be

feasible to combine this sort of forming machine with a projector, though I remember a case of which we have been experimenting, where we have found it extremely difficult to obtain the optical system without distorting the operation of the machine tool but that chiefly applies to the lack of stability generally necessary for projection. There is a very strong tendency—just let me wind up on this point—to combine them to bring the optical, or the measurement system, on to the machine tool and watch the job on the machine, and not wait until the faults and deficiencies are discovered by the inspector.

Another case has just come to my mind; that is in the production of the large light threads for pipes. All those threads are subject to very severe demands; they must be extremely accurate; they must be tight against water from the outside, or from inside instruments and very high pressure; therefore, corresponding gauges are used, with great care and accuracy; in fact we have developed for one firm a hand instrument for checking the pitch. This can be put up to the thread whilst it is in the screw threading machine, and their man can check his pitch and he can check his form with a hand micrometer. He can determine his work perfectly on three measurement instruments on the machine tool.

VISITOR: I would like to ask Mr. Loewen how he would check the diameter for moving wire ranging from 10 to 100 ft.; this depends on the size of the wire. I am sure there is a great demand in the wire trade for such an instrument.

MR. LOEWEN: Yes, there is one optical method but it is only for fine wires up to $\frac{1}{2}$ mm., and that method can be briefly described as follows: A shadow of the wire is drawn on to the screen, or can be observed on a microscope, and by a micrometric movement this shadow can be doubled, which means two shadows of the same bit of wire are put on the screen. After these two shadows are placed, just make their edges coincide, then by the shift of the micrometer screw one shadow is put on top of the other. This movement can then be read on the micrometer to up to one-thousandth of an inch, or one-thousandth of a millemetre, and this can be done irrespective of the position of the wire. It can move of course, not too quickly, because then the unit vibrates with the moving wire unless the wire is read from over guiding pulleys of a certain amount of springing, so that the vibrations are kept within limits. If that can be done, the measurement of those fine wires can be done optically with a very high degree of accuracy; in fact the method is particularly characteristic for very good repeating.

THE PRODUCTION OF THE VACUUM CLEANER.

Paper presented to the Institution, Western Section, by F. B. White, A.M.I.P.E.

THE production of vacuum cleaners in this country has grown in an amazing fashion during the last fifteen years. The grid system is making people electrically minded, and the vacuum cleaner is becoming almost a necessity in every household. In view of the production figures being reached at the present time, it was thought that some of the production methods being adopted might be of interest. At the moment, we are producing five different models, but I propose to concentrate on items pertaining to our biggest popular model and our junior model, although I shall refer to items of interest in other models from time to time.

The large model consists of the main casting assembly, the motor assembly, the handle assembly, and the bag assembly, and I will endeavour to describe some of the methods adapted on each assembly.

The Main Casting Assembly.

The main casting is an aluminium die casting of somewhat intricate design, and considerable difficulty was experienced in the early stages of manufacture, to produce a suitable die. Not only is the casting tied to very close limits and of very light section, but the finish must be free from all blemishes and hair cracks, in order to obviate excessive polishing operations. Prior to the machining operations, the castings are disc ground on the motor seat and the bag flange.

The major machining operations are :—

Op. 1, *Mill Bottom Plate Face.*—This operation is done on a horizontal milling machine, with a special purpose jig having a single lever cam clamp. This cam is provided with suitable adjustment to enable the casting to be held quite rigid without distorting the casting. The production on this operation is 120 per hour.

Op. 2, *Mill Pulley Cover Face.*—This operation is somewhat similar to the first operation, the clamping being again done with

Bristol, February 21, 1936.

a single cam lever, fitted to a swinging latch member. On this operation the table is traversed both vertically and horizontally, the production being 90 units per hour.

Ops. 3 *and* 4, *Mill Pockets and Slots for Agitator Support.*—On these two operations a special purpose twin head attachment is used, the same fixture being used for both operations. The picture shows the cutters in position for op. 4, op. 3 being very similar but with different diameter cutters and cutter positions, obtained by means of suitable distance collars. Here again the clamping is done with one lever only; a cam shaft runs along the back of the casting, and on the shaft being turned, a centre cam contacts with a hardened pad, which forces the complete shaft forward. At the two ends of the shaft, clamping pads are forced against the casting, thereby holding it rigid. On all of these fixtures, the problem has been to produce equipment which will hold a relatively large yet frail casting, rigidly, and without distortion. These last two operations are tied to a tolerance of .003 in. on the 11 in. width.

Before passing it is interesting to note the side relieved slitting saws. These are only .093 in. saws, and as such, are a credit to their makers. The production times on these two operations are 77 per hour and 110 per hour respectively.

The main drilling is done on a rocking jig. This consists of an aluminium casting, with semi-circular steel members attached to the base, in order that it may roll over easily. It enables us to drill all the important holes on three sides, in the one setting. Eleven holes are drilled in this jig, on a Natco multi drilling machine, the rate of production being 45 castings per hour. The remainder of the drilling and tapping is done with relatively simple equipment and is not worthy of comment.

The polishing operations needed to give us the necessary standard of finish consist of:—

Fine all over with 160 emery;
Grease all over with 200-240 emery;
Buff all over with tripoli;
Degrease in special I.C.I. degreasing plant;
Colour buff.

All the castings are 100% inspected for any flaw or discolouration after the polishing operations, to insure that the surface is to our required degree of finish. The castings are then sprayed inside with aluminium lacquer, and passed to the final assembly department.

I might mention that the spray paint shop is supplied with clean filtered air under pressure, to more than compensate for the exhaust system, fitted at the back of each spray bath. It is of great importance that the air circulating in this shop is free from fluff and dirt, as the articles being painted are readily marked during the painting

process, and we have had many rejections by our final inspection department due to particles of dirt settling on the undried painted parts. The remainder of the main casting assembly will be referred to later.

The Motor Assembly.

Consists of the following major items: The motor casing; the armature assembly; the field iron assembly; the motor bottom plate.

The Motor Casing.

This is an aluminium die casting, which is turned complete in one setup, on a Warner & Swasey turret lathe. The case is held in an air chuck, which incidently requires very careful adjustment, as the component is of very light section and easily distorted.

The flange is turned and faced off the cross slide. The location for the bottom plate, the bore for the field irons, the bearing housing with the front and back recess, together with the facing of the front and back of the housing, are all done from the turret. The bearing housing has a tolerance of .0005, and the recess is held quite close limits. This recess is done by a Wimet tipped tool, on a special holder, incorporating an eccentric spindle. The bearing housing is reamed by a kelly type adjustable reamer, and burnished to size by a similar reamer ground cylindrically and highly polished. This method gives a highly polished surface to the bore, and a consistently accurate size. The floor to floor time for this component is 30 seconds. The drilling operations are straight forward multi drilling operations.

The polishing of the case is of interest on this component, in so far as an automatic type of indexing polishing machine is used. The spindle adjacent to the mop is power driven, while the spindle away from the mop and in the loading position is stationary. Immediately the head is indexed round, the head approaching the mop takes up the drive, and the other spindle becomes stationary.

The Armature Assembly.

The component parts go through a multiplicity of operations, prior to reaching the motor shop for winding. The shafts are produced on a four spindle Gridley and ground on "Precimax" grinding machines. We have tried out formed wheels for grinding three or more diameters at once, but have so far not been very successful, as the formers which control the diamond have to be so very accurately made and must retain their sizes within a few tenths of a thou. We find that plunge grinding, as fitted to the new "Lund" machines, the most economical and accurate. The shaft which you see on the screen is one of our heavier shafts, with fairly liberal

tolerances. Our small shafts have a tolerance of .0004 on bearing dies, and we work to considerably closer than tolerances on the portion on which the armature discs are ultimately pressed.

The armature core and field magnet laminations are produced in one tool of the four stage progression type. These tools are operated in the main on a 100 ton gripper feed press, and our production per die grind is in the region of 40,000. This could doubtless be greater, but for the fact that the tolerance on the central pierced hole in the armature core lamination is .0005, which must be rigidly adhered to, as the discs are a press fit on the armature shaft. Another factor preventing long runs on these press tools is that any burrs on the disc prevent a well stacked core with resulting core insulating difficulties.

The material for these laminations, is, in any event an unhappy one to deal with. The treatment of this electric steel, prior to being supplied to us, is such, that, the coating on the steel appears to have definite abrasive qualities. If a lubricant is used on the press, the slugs tend to stick on the punches. If no lubricant is used, there is a decrease in the number off between grinds. The manufacturer of the material, advocate running the stock unlubricated.

So far we have not undertaken slitting our own material, and seeing that four sizes have to be stocked, we realise that it would be profitable for us to consider this operation. Perhaps some of the members here, can give me some information regarding the accuracy obtained on width, the lack of camber in the length, and also whether it is advisable to hold the stock after slitting. I have made various enquiries, and had some very conflicting replies.

The dies themselves are made out of $1\frac{1}{8}$ in. thick die steel, and the stripper plate is made about $\frac{3}{4}$ in. thick, in order to give adequate support to the punches. In view of the expense of the manufacture of the die, only 2 thou. taper per inch is allowed, in order to get long life without excessive burr. The dies are usually completely repunched halfway through the die life, and the dies packed up to their original height. This die height is of considerable importance, as it should be in approximate aligment with the feed height of the gripper mechanism. The punch for piercing the centre hole, which is held to the .0006 tolerance, is made out of high speed steel as we find that this material maintains size, much better than the normal die steel used on the remainder of the punches. It is of course essential, that any new punch which may have to be fitted, is thoroughly demagnetized, as we have experienced considerable trouble, due to this point being overlooked.

The grinding of these dies, is a fairly big job, as we sometimes have three or four tools running at a time. We have purchased a special surface grinder, having a relatively short wide table, hydraulically operated under a 20 by $1\frac{1}{2}$ wheel. This large diameter wheel,

enables us to grind all our dies without removing pillars, or making them unduly short. This machine is of foreign origin, and I cannot but think that there is scope for British manufacturers for this type of machine. The standard type of English machine of this capacity, is much too long in the table, and occupies considerably more floor space, than is justified.

The assembly of the core discs on the shaft, is done on a 7 ton airdraulic press, suitable fixtures being provided to locate the shaft with a series of pins, to control the radial position of the discs. The number of discs on the shaft, is controlled by weight, as well as by stack height.

In order to ensure that the core slots are smooth and dead in line, we assemble these discs as they come from the tool, and great care is taken to seen that the core discs, when blanked out in the press, are caught on two pins ; one in the centre, and one in one of the slots, as they must be assembled on the shaft in this manner.

To check this point, a slight score is made in the die, at the armature core blanking stage, and this score leaves a mark on the blank, which is readily apparent on the assembled core, and should appear as a straight line on the core assembly. Our reason for being so careful about this smooth slot is, that they are insulated by an automatic machine, and rough slots prevent the insulation from being fed in. They also prevent the insulation from accurately fitting the slot, and may subsequently cause loose windings.

The armature core assembly as it is now termed, is next ground on the outside diameter of the core stack, on special fixtures which support the discs. They are next ground in the slots to a specified width, and insulated in the slots by means of the special purpose machines previously referred to, which feed formed up fibre into each slot, and crop off to the specified length. The armature cores are automatically indexed round, as each slot is insulated. The fibre is fed to the machines in roll form, and the cores insulated at approximately 1,400 slots per hour.

The winding of the armatures is done on specially designed machines evolved by my company. They are run at from 600 to 800 revs. per minute, depending upon the model, and automatically stop when the correct number of turns have been wound in each slot. It will be realised that, seeing we are winding five different types of armature, and each type is made in seven to nine different voltages, our machines have to be very adaptable. We can, however, change over any machine to any model and voltage, quite easily, by means of change over cams and gears, and the fitting of the specified winding jaws.

The next operation of importance, is the fitting of the commutator assembly to the armature. This is done under an arbor press in special fixtures, which accurately locate the radial position of the

commutator bars, relative to the armature core slots. The removal of the insulation on the leads prior to connecting to the slots in the commutator, is done in what we term a wire brushing jig. It consists of two steel casehardened shells, which when put on either end of the armature shaft, completely cover the laminations, windings, and commutator. The shells are of such a diameter, as to allow a definite amount of lead wire to be exposed. The two steel shells are then pressed together, thereby gripping the wire, and offered up to a wire brushing machine. By slowly rotating round the complete unit, all the insulation is quickly removed from the leads and the copper wires are thoroughly cleaned prior to soldering. The connecting of lead wires to the lots in the commutator bars after wire brushing, is done on special bench fixture by a number of girls, who by dint of practise, are amazingly accurate and rapid, in this somewhat tedious operation. The soldering of all the leads to the commutator, is done by means of special fluxing and soldering pots. The armature is held in a vertical position, with the commutator seating down on to a special seating in the pot. The flux or solder level, is then raised by means of displacement weight operated by lever. All leads are thus rapidly fluxed and soldered.

The dipping and baking operations on the armature, are done on special purpose racks, so designed as to make all the commutators, when in the dip tank, at the same level, irrespective of model.

The length of immersion in the varnish, is forty-five minutes, and a further forty-five minutes, is allowed for draining, prior to baking. The specific gravity of the varnish, is checked daily, as it is considered of paramount importance, and the oven temperature for baking, maintained at 275° F. by thermostatic control. The baking time for each batch of armature is ten hours.

After the baking is completed, the shafts are cleaned of varnish, the commutators turned, and the micas, undercut on special purpose machines, which have two slitting saws on an arbor, the undercutting being done, two slots at a time. The armature is then subjected to various electrical tests, on special test instruments, prior to going to the motor assembly bench.

Before leaving the armature assembly, I should like to refer to the commutator assemply. This consists of the usual type of commutator sleeve and collar, which clamp the copper and mica segments together in the " vee " grooves, via mica collars. The production of the copper segments without the slightest burr, caused us considerable trouble in the early days of our production. After much experimenting, we are now able to produce 250,000 segments per grind. Our conclusions are :—

(1) That the punch must be well supported in the die prior to cutting. Although our tools are four pillar tools, the support to

the punch is considerably longer than the punch proper.

(2) The stock must be held firmly, when the punch contracts the metal. It must be remembered, that the extruded stock is of "vee" form, and tends to slide, when touched by the punch.

(3) It is preferable to have the die hard, and the punch relatively soft, and to set the press rather deep.

After blanking out, the copper segments are washed, oxidised, and again washed. The reason for oxidising being, that in our soldering method, the complete commutator assembly, is immersed in solder. The solder will only flow into, and adhere to the portion of the copper which has been recently slotted for the lead wire.

The copper and mica segments are assembled one by one into assembly rings. It is a tedious operation, but we have so far been unable to mechanise this assembly. If any of the members present know of any equipment which could be applied to this work, I should be very glad to hear of it. The riveting of the complete assembly is done on a double action air riveter, and is a relatively simple and quick operation. I might mention in passing, that I recently saw a commutator made out of a copper pressing, inserted in bakelite. I should be interested to know if anyone here has had any experience in the manufacture of a commutator, so constructed.

The Field Lamination Assembly.

These differ considerably in various models. The most interesting from a production standpoint consists of 64 laminations. The laminations are held together by means of four rivets, and the operation is completed by two "hits" on a Humphrey's press. We find that this type of press is most suited to the operation, owing to the squeeze action of the toggle mechanism, and slow ram speed at the bottom of the stroke. The correct number of laminations are weighed out on a special weighing machine, and loaded on to a locating spigot, which is fitted to a sliding bottom tool running between guides on a special bed plate. In the first position when the press is tripped, the stack of laminations is coined flat. In the second position, four rivets are inserted, and the press again tripped when the rivets are turned over.

On the up stroke of the press in the second position, the stack is automatically removed from the locating spigot, by means of spring loaded claws attached to the top tool. It was found essential to coin this stack in order to get a satisfactory turn over on the rivets. All field lamination assemblies are ground on the outside diameters, on special grinding mandrels accommodating six to eight assemblies. The field coils are wound on suitable formers, and after waxing, are taped, dipped, and baked.

A special black plastic varnish is used, where again the specific gravity is the subject of continual test. The immersion time for the

coils is forty-five minutes, and the baking time, two hours at 200°F.

They are then heated up again slightly, on a hot plate, prior to forming round the field irons, on special bench fixtures, which are connected to an electrical circuit, which checks each coil for continuity test.

The Motor Bottom Plate.

On both of the models to which we are mainly referring, these are light aluminium die castings. The operations performed on them are relatively simple, our major troubles being again the method of chucking without distortion. The bearing housings are burnished by means of a modified adjustable six flute reamer, in a similar fashion to that used on the motor casing.

The Motor Assembly.

The building up of the motors is done on assembly benches, equipped with miscellaneous fixtures, air screw drivers, and special purpose equipment. At the end of the benches are running-in racks, on which every motor is run for a period of approximately twenty minutes, prior to going on to the test board.

The running-in rack consists of an angle iron frame, on which wooden runners are fixed. Copper strips suitably protected are fitted to the runners. The motors proper are located in special trucks, four motors to each truck. By means of suitable connections, and the metal wheels on the trucks, all the motors on each truck are automatically switched on, as soon as the truck contacts with the strips.

On completion of the running-in period, each motor is tested individually at the correct voltage for current consumption, speed, noise, and vibration. The speed is checked by means of a reed type vibration tachometer, which readily indicates the r.p.m. of any motor against which it is placed. Vibration is a point on which a high standard is rigidly maintained, and fan balance is a point of vital importance. A special purpose machine has been evolved, which enables quick yet accurate balancing to be accomplished.

The complete motors, after the tests referred to, are shipped to the final assembly department. This department consists of a series of sub-assembly benches and final assembly lines. The most important sub-assemblies fitted in this department as part of the main casting assembly, are the agitator assembly and agitator support assembly. The body of the first unit, is a steel or aluminium shell, depending upon the model, in which are two slots diametrically opposite, on each side of the pulley groove. Into these slots are fitted the brushes which are reversible to allow for brush wear. Around the periphery of the shell are riveted four spiral bars. These bars are known as agitator bars, or beater bars, and the method of

manufacture is a little unusual. Round edged stock is purchased in strip form, and cropped off to length, as the first operation.

In the second operation it is formed to a U section in a power press. The third operation is to form the spiral to suit the agitator body. The lead of the spiral must be accurate, as the bars must sit down on to the agitator for their whole length, and they must be in alignment with the rivet holes, which are drilled or pierced in the agitator bodies. The spiralling is perfomed on a power press, by means of the tool to be illustrated. The U stock from the previous operation is passed through a helical groove out in a block, in which is a half-circle corresponding to the diameter of the agitator body. The top tool is a male half-circle which fits the lower half. The press is run on the repeat, and a series of blows are delivered to the bar, as it is passed through the tool. This method, although it would appear to be somewhat crude, enables us to spiral accurately all our beater bars. It is possible that some of the members present may have encountered a similar form to manufacture in quantities. If so, I should be glad to hear comments of the methods adopted, during the discussion.

The welding of the rivets to the beater bars is of interest, in so far as the rivets have to be accurately located, in order to mate up with the holes in the body, to which they are ultimately riveted. A special fixture enables this to be done accurately and quickly. After welding, the bars are fined with a 140 grit wheel, in the polishing shop, and case hardened in a cyanide bath, the immersion time being approximately thirty minutes, and a subsequent dip off in oil. The bars after cleaning are next greased on a spiral stitched wheel, using 180 Tripoli at 2,150 r.p.m., then degreased, put through the nickel vat, and finally colour buffed.

It may appear that these bars go through a number of unnecessary operations, but it must be remembered that these bars are continually in contact with the carpet. It is therefore essential that the bars are hard and highly polished, in order that no possible damage can be done to the carpet. It is for this reason that round-edged stock is used, at considerable cost, as flat stock might leave a sharp edge abutting the agitator body, which might do damage, or collect cottons or litter. The bars are riveted on to the agitator body, on a special horn type press, and the remainder of the assembly, consisting of the agitator ends, in which the ball bearings are housed; the shaft and the thread guards are ordinary bench assembly operations.

The agitator support assembly is of interest in so far as it consists of five items, spot welded together. This assembly must b accurate for alignment, as it has to fit losely into the main casting, and house the agitator assembly. The complete support is cadmium-plated after welding.

The final assembly of the cleaner is done on a series of hopper fed, power driven riveting machines, and a series of bench operations.

The riveting machines are grouped in such a manner, that a main casting is taken from the storage rack, and the oprator passes from one machine to the next, adding a sub-assembly, or parts, at each machine. the number of men in the line dependin upon the production requirements of the particular model for which the machines are set up. These riveting machines are such that spring pilots locate in the rivet holes. When the rivet descends, the pilot recedes into the anvil, to a positive stop.

The stop position, relative to the anvil, being the secret of successful turn-over of the rivet. The moulded rubber furniture guards, round our main castings, are riveted on by these machines, the rivet being driven through the rubber into the hole in the casting, and turned over. The motor assembly and ball assembly, and other minor assemblies, are added to the main casting assembly, on the final assembly bench.

From this point each cleaner is put on to a running up rack, prior to a final test. This rack is so constructed that the cleaners are run under working conditions, as the carpet on which they are placed is built into the rack in the form of a running belt, and is traversed slowly under the cleaners. Each cleaner has from fifteen to twenty minutes of running up prior to the final suction test, current consumption, vibration, and noise tests. All cleaners are then inspected for nozzle adjustment heights, brush and beater bar extension, handle control details, wheel levels, and general appearance. A rigid standard is maintained on all of these major items, and I might mention that on this inspection there are 87 definitely recognised points which may be the subject of rejection.

Daily inspection reports, showing the number of cleaners rejected against each item, is issued by the final inspection department. All cleaners, after passing final test, are hand polished to remove finger marks, put into flannel protecting bags, and packed into cartons together with their dust bags.

The manufacture of the dust bags has one or two points of interest. The material has to be such that it will not only permit air to pass through it without undue back pressure, but it must also prevent the finest dust from passing through. Our English suppliers were experimenting for approximately twelve months before they were able to produce a weave to our engineering department's requirements. This department has evolved ingenious methods by which they can readily check the porosity and back pressure factors of our bag material, and samples of each supply are submitted to this test to ensure that the standard is maintained. The bags are cut out to a template, approximately 50 at a time.

by means of an Eastman cloth cutting machine, on a long cutting out bench, after which each bag is then stencilled.

The stencilling is done through special silk screens. The mesh of the silk in these screens plays an important part in the ultimate result obtained. The screens must also be treated with a special type of shellac, which is not affected by paint thinners. The paint also has to be of such a nature that it will dry rapidly, and yet not crack when the bag is crumpled. In consequence, all paint is mixed many days ahead, prior to requirements, to ensure thorough impregnation of the pigment with the base oil. After stencilling, each bag is passed to the sewing machine bench, where they pass through three different types of machines, some of which sew, bind, and trim at the same time.

Handle Production.

In the manufacture of our handles, certain operations are, I think, interesting. They are produced out of $1\frac{1}{8}$ in. diameter welded steel tubes. The tubes are first cut off to length in the machine shop. They are next fined on a centreless grinding attachment fitted to one of our standard polishing spindles. This operation is really a cleaning operation, in preparation for receiving the paint. The slots for the switch and bag roller housings are done together on a double horned press tool.

Not only have the slots to be cut accurately to size, but the ends of the switch housing slots have to be set down at the ends to form suitable platforms for the switch cover plates. In each platform an extruded hole has been pierced. This extruding is important, as the hole is subsequently tapped.

The complete piercing and forming operations are performed at one set up on the press in four operations. The slots are quite wide relative to the diameter of the tube, the slots being $\frac{7}{8}$ in. while the inside diameter of the tube is $1^1/_{16}$ in. This necessitates the horn on the tool being somewhat less than $1^1/_{16}$ in., which makes it impossible to let in a die insert, to cut out the $\frac{7}{8}$ in. width of material. The method we have adopted is to cut slots slightly greater than a third of the width specified, at the first trip of the press ; the handle tube is then turned round on the horn to a stop, and the press again tripped. The tube then has two sets of slots, separated by a strip of metal narrower than the punch and die. This strip of metal is removed by again turning the handle on the horn, and sighting the strip over the die aperture. The press is tripped for the third time, which completes the cut out of the slots. This sequence of operations on the first horn, although taking some time to describe, is actually quite quick in operation.

The operation of forming the flats, and piercing the extruded holes on the second horn, is done with one trip of the press. The horn having sliding forming dies, operated from the top tool, the dies receding into the horn after forming the flats and the extrusions in order to remove the handle. The remainder of the holes are pierced on a tool, having punches coming from the sides by cam operation, and punches in the top tool. Here again the problem of die inserts in the small die horn, constituted something of a problem, particularly where two holes were diametrically opposite, as the slugs tended to pile up with resulting broken punches. The difficulties were overcome by having the one punch in advance of the other, and suitable shear added to the punches.

The forming of the curve at the end of the handle is done on a special fixture attached to a power press. The handle is pushed onto a horn and clamped down in a somewhat similar fashion to the standard type pipe bending machine. The clamping member is on a quadrant, which is connected to the crank of the press by a connecting rod. Immediately the press is tripped, the handle is drawn off the horn round the formed seating on the quadrant. This operation is considerably quicker than can be obtained from an ordinary pipe bending machine, and the equipment is readily adaptable for other handles of different size and radius.

After the machine shop operations, the handles are dip painted and baked, and passed to the assembly bench. Here the plug bases, the leads, handle insulators, handle locators, the switches, and the bag roller housings are added, together with the rubber grip, and the cord storage clips. This latter item is of some interest in that it is produced out of .032 sheet steel and formed complete in one operation. It is first pierced and blanked in a straight forward blanking tool. The second and final operation, prior to painting or plating, is done on a press tool having suitable spring locations, which recede under the top tool, and enable us to form the part complete in the one blow.

After the assembly the handles are passed to final test, where each handle undergoes a lamp test, and a 1,000 volt earth test, prior to being packed into special cartons.

The Dusting Tools used with our machines consist of straight and curved welded steel tubes with quick release connections, so that they can be readily connected to the hose or to the dusting tool brush or blower. I have been unable to obtain a slide showing this assembly in detail, but as a point of interest, have brought a slide showing the first operation on the cover for the dusting tool catch. This tool is a four stage progression tool, and the material used is .025 sheet brass. These covers pass through a further

forming operation, to form the ears to the shape of the tube, prior to plating.

Wherever possible on all our press items, we favour making a progression type tool, either by piercing and forming, and ultimately blanking, or by blanking first, and returning the blank to the stock, by means of a pressure pad and subsequently forming.

Final Inspection and Test Department.

This department, which is directly under the engineering department, controls the standard of our products. A test laboratory enables them to make comprehensive tests on all parts subject to wear as well as all forms of electrical tests.

The life test racks will accommodate approximately 40 machines, which are operated under the equivalent of working conditions on running carpets. The machines are switched on and off automatically, the running periods being five and three-quarter minutes in seven minutes. On these test machines, motor bearings, agitator bearings, commutators, carbon brushes, belts, and dirt finder lamps, etc., are tested. The items under test are inspected at periods of 100 hours, and test reports made out, the length of the test being anything from 100 hours to 1,700 hours, depending upon the item under test. It is only after such tests, that our purchase department is permitted to add the suppliers name to our approved source of supply card.

Standard production cleaners are submitted to life test, on a percentage inspection basis, on these racks, and reports made out on points of failure for the benefit of the production department.

Numerous test devices have been evolved to test the life of other units on the cleaners. Switches are given a life test on a special machine, which switches them "on" and "off" continuously, the switch being loaded all the time, by means of a lamp, so as to reproduce the normal sparking of the contacts. The switches, operating continuously, should make and break their contacts 12,000 times without signs of failure.

The handle cord is subjected to severe tests to ensure that it will give service in operation. Six samples are tested at a time, each carrying the full electrical load. The winding machine shown in the picture, winds and unwinds the cords on the clips a specified number of times, which is the estimated equivalent of twenty years' service. The cord is also tested in the ageing oven for bloom test. This bloom test is also used extensively on all the other rubber parts.

Apart from the many other laboratory tests, my company have instituted a home test scheme. By this method new models are tested out at home by the factory superintendents and departmental heads. As new models are produced, they are sent round to the

houses of the people concerned, and the previous model collected. After a period of trial, reports are collected, on each test cleaner, and minor troubles are thereby noted and eliminated.

In conclusion, I should like to acknowledge with thanks the permission of my directors to deliver this paper. When asked to undertake this task in the Bristol area I did so with some misgiving, as I realised that I was coming to an engineering centre, renowned for its precision products. Whilst I realise that our product may not compare with the intricacy of your aero engineers, I felt that our products were certainly cleaner than most.

Discussion.

MR. DANIELS: There are two or three points I should like explained a little more clearly. First of all Mr. White spoke of the steel blades for the stator and rotor and the trouble they experienced with scale. I always thought these were made of a special charcoal iron and that by using this the trouble experienced with steel was overcome. I should like a little more explanation as to how the spirals were made on the rig the speaker illustrated. It seemed to me to be a very ingenious application which might be applied in a good many other things. Another thing has occurred to me. We are living in an age of plastics. I get an opportunity of going into a good many kinds of factories where this kind of material is used, and it seemed to me that certain parts of that machine were essentially suitable for plastic material. I do not believe in introducing plastic material where aluminium, steel, or brass is the most suitable medium, but I know a good deal of plastic work is now done and it struck me that a good many parts of the lecturer's machine were essentially suitable for plastic material. Some of these materials are very strong and can be beaten with a hammer, and I do know certain parts of a cleaner might be banged against the wall or furniture.

MR. WHITE: With regard to the scale on the electric steel, I can assure you that from my point of view, it is a tremendous problem. There are not many suppliers and if you ask them exactly what it is they won't tell you. It is treated and what the treatment actually is, I don't know, but it is definitely abrasive, and supplies seem to vary, because on one batch I have had a 40,000 to 60,000 run and another batch has dropped down to 20,000 to 25,000. All our specifications actually come from America, and I am getting supplies from America to see what sort of material they are using. I think supplies tend to fluctuate, and the amount of treatment varies on the steel.

With regard to the question of the spirals, there is a hardened steel block with a half circle cut into it the same radius as the agitator body. This half circle has a helical groove cut in it. The stock to be spiralled is fitted into the helical groove and the press run on the repeat. The stock receives about 25 blows in passing through the tool.

We have been considering the use of bakelite, and certain experiments are being carried out, and it is highly probable certain pieces

will be incorporated later. I was in touch with a German some time ago, and he showed me some articles made in a plastic material about .025 in. thick, and he threw them about all over my office to demonstrate how unbreakable they were. The material prior to curing looked like a sheet of brown paper. He claimed you could blank it out in the required sizes in a power press. I certainly think the machine offers tremendous scope for the application of this material, but we have a considerable amount of capital tied up on diecasting equipment. The machines required are very expensive units and the capital involved has to be considered.

MR. DANIELS : I was very struck by the amount of punching and pressing you do rather than machining. It must mean a tremendous amount of equipment to get accuracy.

MR. WHITE : We have got something like 40 to 50 presses, producing parts with many tolerances of .001 and .0005. We can turn out our parts much faster by pressing.

MR. GLOVER : Speaking of the spiral strips for the agitator, I think you might fit a hardened copper or steel rod. This would be cheaper than pressing the actual strips from sheeting and riveting them on to the rod plus spot welding.

MR. WHITE : One of the difficulties with that is you would have to mill a spiral slot in the agitator body. We never mill if we can pierce. The milling operation would be fairly costly. The agitator body is of very light section.

MR. GLOVER : Could you not cut the spiral slot like you cut a thread? After you had cut the slot you could lap in the rod to follow the spiral channel on the agitator body.

MR. WHITE : To do that you have got to have a very plastic material. The strip has to be dead hard because of the work it has to do and produced in bar as you suggest it would give a series of troubles. Parts like beater bars must be dead hard and smooth. We polish them and cadmium and nickle plate them. We have experimented with a new way of forming the stock round a mandrel, but the difficulty is to eject it after it is formed.

MR. AUST : Does not the speaker think chromium plating would be a better finish than nickel?

MR. WHITE : We have considered the possibility of chromium finish, but we are afraid of its tendency to flake.

MR. AUST : If you have good plating you would not get that trouble.

MR. WHITE : Quite frankly, I have not had much experience with chromium, and I think the suggestion a good one, but my experience is that there is a liability to flaking which would mean sharp edges which might damage carpets. I think chromium would be adopted provided we could get a guarantee it would not peel. I advocated chromium plating the fan pulley, my reason being that

it has to run within .008 in. This is not easy, as the part is hardened and sometimes distortion takes place. I tried to obviate hardening by suggesting chromium plating, but it was turned down because of possible flaking. I think the suggestion is sound if we can get chromium to be really lasting.

MR. SELVEY: How is the lamination strip fed into the press—is it by hand or is it by a trigger feed?

MR. WHITE: For the lamination strip we have a gripper feed. That is a Humphrey's press with a gripper mechanism. On some old machines we occasionally use hand feed with a trigger stop. but on our modern machines we have a gripper feed automatically feeding the stock along. We have also a means whereby the gripper mechanism is released for a very short portion of the stroke. This release is not fitted unless specified. I mentioned that it is desirable to get the die height approximately level with the feed height. This is never quite in line and it is for this reason you must release the stock and let you pilots definitely locate the stock.

MR. SELVEY: I asked because I have triedh itch feeds and cannot get them to work. They will slip occasionally and won't release when they ought, and we have gone back to hand feed, the other feeds being too expensive for our quantities in production.

MR. WHITE: The roller feed attachment is very expensive, and none of the press suppliers make a press so that you can fit the roll feed itself without returning the press to the makers.

MR. STONE: I was very interested to hear the speaker say in one part of his lecture that he used the die hard and the punch soft. I should like a little further explanation of that.

MR. WHITE: One reason for that is that the copper segment is extruded stock and it is very essential that you do not have anything in the nature of burrs which might pierce the mica insulation. The punch must be made to fit really tight. You can upset the punch when the tool goes up for grinding, usually after producing some 300,000 pieces. When grinding you get slightly more clearance, and by peening the punch you take up what would otherwise be slightly increased clearance.

MR. DANIELS: Does the punch expand sufficiently to take up the wear?

MR. WHITE: The draft on the die is very small and all the time the punch tends to build up and actually sheers itself to shape.

MR. STONE: I take it you mean, glass hard for the die and fairly hard for the punch?

MR. WHITE: Yes, the punch must be reasonably hard.

MR. DANIELS: What type of steel do you use for the dies? Have you used Baflour's steel?

MR. WHITE: We have tried various types. We find that for a heavy abrasive type of material on the laminations for example,

and with a heavy loaded die the best is Jones & Colners N.R.W. or Cooks special. I have not used Belfast stock. We also use the K.E. brands for light types of tools.

MR. MAURICE : Have you any instruments for testing noise on final inspection ?

MR. WHITE : I must say definitely no. Noise is really vibration. We have tried instruments for testing vibration, but they, at the moment, are not very successful, because most of the instruments are too sensitive. We had a Zeiss instrument and it checked the vibrations of the building. Actually noise standard is very difficult to judge. We have to work very largely by the trained ears of our test department. If you know of any instruments which can be used commercially on a production basis I should be interested to hear of them.

MR. GLOVER : I do not wish to criticise the design of your machine, but on the " Junior Model," the drive seems to be very primitive. A friend of mine has one. It is an excellent machine, but I was surprised at Hoover's using a drive with a plain rubber belt. The belt seems to break away too quickly owing to the high rate of revolutions which set up heat and causes the rubber to become plastic and break away at the vulcanised joint. Furthermore, the centres of the drive are very short.

MR. WHITE : The problem of driving the agitator is a difficult one. At one time we tried a more positive drive but there are certain disadvantages. The drive must be such that in the event of anything jamming the agitator drive will slip and thus not damage the motor. The rubber belt drive does therefore save the possibility of serious trouble.

We had experienced slight troubles on our Junior model but by modification to the pulley they were soon overcome. We also experienced difficulty in obtaining satistactory English supplies of rubber belts. The American made belts which we had previously used were doubtless of better quality.

MR. DANIELS : With regard to the point raised in regard to rubber. We are using a machine made in America, and we use a rubber coupling immersed in oil. We tried to get this rubber in this country, but we have had to go back to the States because we cannot get rubber made here which will resist the torque and at the same time work in oil.

MR. WHITE : That is so, on rubber the Americans are ahead at present. We have been trying to get satin finish on rubber parts we require on the handle. The handle you saw on the screen had no finishing parts on. The handle on the machine has got a rubber grip as a safety margin. That rubber grip is sprayed to give a nice finish as the rubber people here cannot give the same finish as the Americans. The same thing applies to impregnated

canvas and the lead wire which was illustrated on the testing machine. When the company on this side started in 1933 we had to receive supplies from America for quite a time before we could get a satisfactory supply in this country.

MR. FOSTER: What means do you employ for testing and determining the life of rubber?

MR. WHITE: That depends on what the rubber is doing. The handle flex is given a winding test only to make sure it is sufficiently flexible to resist winding and unwinding. We have also a "bloom" test as the English people cannot supply us with a rubber that looks satisfactory without lacquer. We only keep our rubber in stock a short time prior to lacquering because of bloom. We have two methods of dealing with supplies, an ageing test under slow heat for testing the material which comes in, and also we have a scheme whereby no rubber is allowed to remain in store for more than a month so as to ensure there is no change due to age or bloom. The American rubber does not age and will retain its nice appearance.

MR. FOSTER: Is your rubber stored in constant temperature?

MR. WHITE: Yes, the whole factory is kept at a constant temperature. It is very seldom below 63° or 65°. The rubber store is heated in the same way as the rest of the factory.

MR. FOSTER: Do you not think bloom might be due to temperature differences and a damp atmosphere?

MR. WHITE: Quite possibly this might be so, and I think it would be well worth while experimenting.

MR. ATTWOOD: Have you ever experienced any trouble due to distortion in hardening, and do you have any intermediate inspection on parts going through the shops?

MR. WHITE: The only trouble we have had with distortion is on the fan pulley which has to fit on to the armature shaft and in the hardening of this pulley we did get distortion. Now instead of completely immersing this pulley in the cyanide we immerse it for about $\frac{1}{4}$ in. and dip off in oil to obviate distortion, and by that means we have overcome distortion. The beater bars we managed to retain fairly well. I think this rather means that the hammering effect given when fitting the spiral does help the heat treatment. We have some intermediate inspection on parts going through the shops; we also have floor inspectors going all round the factory and every part is subject to a percentage inspection, some to 100% inspection. When a new batch is started off and the first half-dozen is produced, the man must not proceed until these are "O.K.ed" by an inspector. This applies to every machine operation on each component.

MR. AUST: With regard to plating, you say you nickel on cadmium. Cadmium is pretty dear. Would it not be satisfactory to nickel on zinc?

MR. WHITE : It might possibly be. It has been suggested before, but there again the question of specification arises.

MR. DANIEL : Is not zinc a poor base ?

MR. WHITE : Yes, and all our parts are cadmium or nickel.

MR. AUST : There is a considerable difference in price. Lately cadmium has gone up tremendously, as the market has been cornered, and many firms have had to give it up owing to the high price. I should say copper and chrome is almost as cheap.

MR. WHITE : Thank you. I will make a note of that.

MR. DANIELS : I thought it was always specified for a first-class finish you must have a copper base and then nickel. If you nickel on the material do you not always get trouble with peeling ?

MR. AUST : As a matter of fact, in Sheffield in the cycle trade, etc., they nickel straight on to the steel base. I wonder to what extent they have to do polishing.

MR. ATTWOOD : The secret is in the etching.

MR. DANIELS : Is there not some mysterious process something like anodic treatment to which parts can be subjected before nickel plating ?

MR. WHITE : I think there are certain acid and electrolic methods, but I really do not know much about them.

MR. KENWORTHY (who occupied the Chair) : I think we have had a very interesting discussion and this has brought out quite a number of points. There are one or two points I made a note of which struck me as being of interest. The first is the method which Mr. White described of burnishing holes. He has emphasised the question of trying to prevent distortion. Polishing by means of a Kelley type reamer seems to be an operation which must develop some heat and some distortion. I don't know if that has been experienced. Presumably not. He mentions that after punching out the laminations they are located so that they will assemble on the cores in the same manner as they were punched out. I don't know if that means that the cores are not interchangeable. Another item which sounds a little bit strange to me, is " colour buffing." I would like to know what he means by this. Another question relating to distortion is in reference to the jig he showed us in which the agitator support consists of five parts welded together. It seems rather extraordinary there is no distortion on those frames after spot welding, and presumably these frames have to be accurate in regard to align ment. On one of the slides he showed assembling machines for riveting parts together and he stated the operators went round with various components from one machine to another. That seems rather a new application of line assembly. Instead of the pieces moving down the line to the various men, the man himself moves down the line.

MR. WHITE : With regard to the Kelly type reamer, we have the reamer very highly polished and it actually burnishes up to size and definitely gives to .0005 in. bore and gives a mirror finish without distortion. On the question of the accuracy of the die, I rather wondered if that point would be picked out. Actually the cores will never really match up. It is an extremely tedious job for the tool maker to cut 25 slots in $1\frac{1}{8}$ in. material, we file them as nearly as we can but they are a matter of thous. different. So we have the laminations packed up to ensure they go on the core the same way as they are punched. We have to get an accurate fit and it is worth while taking trouble. With regard to " colour buffing." We treat our mops with abrasives, and we find we get a better polish on aluminium by treating the mop with a certain colour material. With regard to the question of welding the agitator assembly, we spot weld one spot on each corner very rapidly. It does distort slightly but when it is fitted into the casing it is set into shape as it is assembled. With regard to the question of the assembly machines and a man going round in the line, the picture is rather an old one. We have now three assembly lines ; instead of their being in a circle as in the picture they are in a straight line. We have probably four men on each line. The first man will pick a certain component up, walk to one machine, and then on to the next, and so on, until he reaches the next man when he will hand it to him, the other man will go on to the next, and so on, until the assembly is completed. We find this method very rapid, there are 10 riveting machines before the assembly goes to the final assembly bench. It is a light component and as such lends itself to the man walking along and picking it up.

A cordial vote of thanks to Mr. White was adopted.